



Factors affecting growth of Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*) in alpine lakes, of the Absaroka-Beartooth Wilderness, Montana
by Richard Kenneth Stiff

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Fish and Wildlife Management
Montana State University
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Abstract:

The purpose of this study was to determine factors responsible for poor growth of Yellowstone Cutthroat Trout in Kookoo Lake, an alpine lake in the Absaroka-Beartooth (A-B) Wilderness, and to examine factors related to the variation in growth rates of cutthroat trout in other A-B Wilderness lakes. The influence of these factors on growth rates should be considered when stocking alpine lakes. Major objectives of this study were to use historical data from 1956-1997 for 71 A-B lakes stocked with Yellowstone Cutthroat Trout to (1) establish mean age-length relationships, (2) correlate growth rates to stocking sequence, stocking density, and physical characteristics of alpine lakes, and to use field methods to (3) compare physiochemical and biological characteristics of two similar A-B lakes that exhibit contrasting growth rates. Based on stocking and gill net records obtained from the Montana Fish, Wildlife and Parks mean lengths were established for ages 1-10 for cutthroat trout. Stocking density, stocking sequence, lake elevation, depth, area, and volume were correlated with growth rates using stepwise multiple regression, and were examined for trends. Kookoo Lake and Triangle Lake were examined to establish profiles for temperature, dissolved oxygen, pH, nitrate, ammonia, phosphate, and chlorophyll-a concentration. Biological activity was compared using diel fluctuations of dissolved oxygen and pH. Heavy metal concentrations were noted at the surface and bottom. Light penetration was determined from Secchi measurements. Discharge was measured, and flushing rates calculated. Benthos and zooplankton were counted and identified. Fish were stocked in both lakes at 247/ha in 1994, but were absent from Triangle Lake in 1995. Growth and health of fish in Kookoo Lake was monitored through 1997. Stocking sequence ($p=0.026$), stocking density by area ($p=0.003$), lake elevation ($p=0.007$), and lake volume ($p=0.025$) correlated negatively with growth. Biological productivity was lower in Kookoo Lake compared to Triangle Lake as measured by dissolved oxygen flux (0.70 to 0.97 mg/L.h, respectively) and carbon dioxide flux (0.007 to 0.031 mg/L.h, respectively). Extremely high flushing rates of 2-9 d in Kookoo Lake caused a washout of nutrients and organisms lowering productivity when compared to Triangle Lake, although nitrogen levels were consistently higher in Kookoo Lake. The nitrogen:phosphorus atom ratios of Kookoo Lake (23:1-June 94, 20:1-July 94 and 9:1 August 94) indicated a mainly phosphorus limited system, while Triangle Lake was limited by nitrogen concentration's (3:1, 12:1 and 7:1). Zooplankton densities were five to ten times higher in Triangle Lake where the population was dominated by cladocerans, while the smaller Kookoo Lake population was dominated by copepods. The lower productivity of Kookoo Lake probably made the zooplankton population more susceptible to the high trout stocking density initially used, resulting in an altered zooplankton community, excluding most cladocerans, and reducing population density. Growth rates are highly variable in alpine lakes with stocking density, stocking sequence, lake elevation, lake depth, lake area, and lake volume accounting for only 9.8% of difference in growth. This study indicates that flushing rate also has an impact on productivity in alpine lakes. Further study of flushing rate and other factors that may influence growth is needed. Adjustments of trout stocking densities can be used to vary growth rates, but consideration of elevation, depth, area, volume, discharge and flushing of individual lakes would provide a more predictable result.

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A thesis submitted in partial fulfillment
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MONTANA STATE UNIVERSITY

Bozeman, Montana

December 1998

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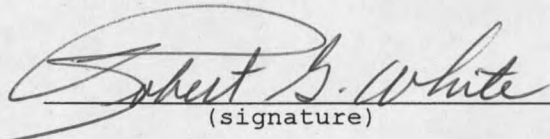
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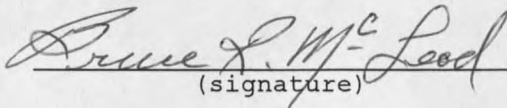
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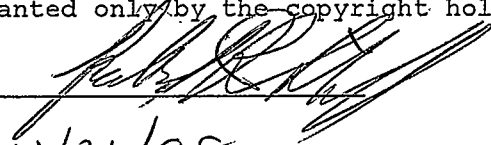
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This work is lovingly dedicated to my two children, Carrie Jo, and Rikki Rae, who were forced to sacrifice spending time with their Daddy while he worked on this project, and to my parents who have faithfully supported me through all of my endeavors.

ACKNOWLEDGMENTS

Many individuals and organizations deserve recognition for their contributions to this project. Jeff Hooker provided the encouragement, advice and support to get this project off the ground. Dr. Robert White, of MSU's Cooperative Fisheries Unit, took on this project as my advisor, when already supervising numerous other graduate projects. Deanna Topp, as always, provided support enabling me to complete both my project and graduate studies. Dr. John Priscu provided the insights necessary to conduct limnological assessments. Dr. Tom McMahon and Dr. Robert Moore each agreed to serve on my advisory committee. The DOE MORE grant administrators, Dr. Hugo Schmidt of MSU and Dr. Jerry Bromenschenk of UM provided financial support. The DOE Alliance Program provided financial support for equipment and personnel during much of this research. Alliance contributors were Dr. Marshal Adams, Dr. Art Stewart, Dr. Ed Aebischer, Dr. Mark Greeley, and Clarabeth Johnson. The Montana Fish, Wildlife and Parks (FWP) allowed this project to become a reality, with the support of Jim Darling, Mike Vaughn, Ken Frazer, and Mike Poore. Many FWP employees worked directly on this project: Jeff Scott, Dave Hergenrider and Rich Furber packed in equipment on horses; Dave Stonehocker, Steve Dalbey, and Rob Charette helped at the lakes; Daryl Hodges, of the Yellowstone River Hatchery provided the fish to be stocked in 1994. Student interns were Thomas Ten Bear, Dee J. Bad Bear, Gayle Lam and Ladd Nolin. Little Big Horn College provided financial support and release time.

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ABSTRACT

The purpose of this study was to determine factors responsible for poor growth of Yellowstone Cutthroat Trout in Kookoo Lake, an alpine lake in the Absaroka-Beartooth (A-B) Wilderness, and to examine factors related to the variation in growth rates of cutthroat trout in other A-B Wilderness lakes. The influence of these factors on growth rates should be considered when stocking alpine lakes. Major objectives of this study were to use historical data from 1956-1997 for 71 A-B lakes stocked with Yellowstone Cutthroat Trout to (1) establish mean age-length relationships, (2) correlate growth rates to stocking sequence, stocking density, and physical characteristics of alpine lakes, and to use field methods to (3) compare physiochemical and biological characteristics of two similar A-B lakes that exhibit contrasting growth rates. Based on stocking and gill net records obtained from the Montana Fish, Wildlife and Parks mean lengths were established for ages 1-10 for cutthroat trout. Stocking density, stocking sequence, lake elevation, depth, area, and volume were correlated with growth rates using stepwise multiple regression, and were examined for trends. Kookoo Lake and Triangle Lake were examined to establish profiles for temperature, dissolved oxygen, pH, nitrate, ammonia, phosphate, and chlorophyll-a concentration. Biological activity was compared using diel fluctuations of dissolved oxygen and pH. Heavy metal concentrations were noted at the surface and bottom. Light penetration was determined from Secchi measurements. Discharge was measured, and flushing rates calculated. Benthos and zooplankton were counted and identified. Fish were stocked in both lakes at 247/ha in 1994, but were absent from Triangle Lake in 1995. Growth and health of fish in Kookoo Lake was monitored through 1997. Stocking sequence ($p=0.026$), stocking density by area ($p=0.003$), lake elevation ($p=0.007$), and lake volume ($p=0.025$) correlated negatively with growth. Biological productivity was lower in Kookoo Lake compared to Triangle Lake as measured by dissolved oxygen flux (0.70 to 0.97 mg/L.h, respectively) and carbon dioxide flux (0.007 to 0.031 mg/L.h, respectively). Extremely high flushing rates of 2-9 d in Kookoo Lake caused a washout of nutrients and organisms lowering productivity when compared to Triangle Lake, although nitrogen levels were consistently higher in Kookoo Lake. The nitrogen:phosphorus atom ratios of Kookoo Lake (23:1-June 94, 20:1-July 94 and 9:1 August 94) indicated a mainly phosphorus limited system, while Triangle Lake was limited by nitrogen concentrations (3:1, 12:1 and 7:1). Zooplankton densities were five to ten times higher in Triangle Lake where the population was dominated by cladocerans, while the smaller Kookoo Lake population was dominated by copepods. The lower productivity of Kookoo Lake probably made the zooplankton population more susceptible to the high trout stocking density initially used, resulting in an altered zooplankton community, excluding most cladocerans, and reducing population density. Growth rates are highly variable in alpine lakes with stocking density, stocking sequence, lake elevation, lake depth, lake area, and lake volume accounting for only 9.8% of difference in growth. This study indicates that flushing rate also has an impact on productivity in alpine lakes. Further study of flushing rate and other factors that may influence growth is needed. Adjustments of trout stocking densities can be used to vary growth rates, but consideration of elevation, depth, area, volume, discharge and flushing of individual lakes would provide a more predictable result.

CHAPTER 1

INTRODUCTION

Historical Overview

The fishery in the Absaroka-Beartooth (A-B) Wilderness is distributed over nearly 350 lakes and associated streams. Over 600 additional lakes within this wilderness have no fish. With the possible exception of four lakes within the Slough Creek drainage, all fish populations originate from introductions.

Stocking of A-B lakes began in the 1930's with the introduction of brook trout *Salvelinus fontinalis* because of its hardiness, and minimal spawning requirements (Marcuson 1976). Subsequent introductions included rainbow trout *Oncorhynchus mykiss*, golden trout *Oncorhynchus aguabonita*, and Arctic grayling *Thymallus arcticus*. Most A-B Wilderness lakes are now stocked with Yellowstone cutthroat trout, *Oncorhynchus clarki bouvieri* (Stiff 1995b) due to the location within the original range of the species, and their availability.

While early introductions focused on establishing reproducing fish populations, many lakes lacked suitable gravel for spawning. Currently, lakes without self-sustaining populations are managed as put-grow-and-take fisheries. This management has a smaller impact on other species in the community, compared to reproducing populations (Hoffman et al. 1996). Since trout predation alters the zooplankton community by removing large zooplankton species (Gliwicz 1984; Leuke 1990; Chess et al. 1993; Hoffman et al. 1996), stocking cycles can be adjusted to allow original zooplankton community structure to be reestablished. Stocking densities may also be adjusted to minimize the impact on the local fauna, and to alter the growth rates of fish.

In some cases trout grow poorly, even when low stocking densities are used. For these cases, identifying factors influencing growth rates would allow for better management. Nelson (1987) noted that elevation affected growth rates of rainbow trout as did Chamberlain and Hubert (1996) with brook trout. Maximum lake depth is another factor that has been identified with shallower lakes exhibiting better growth of trout (Chamberlain and Hubert 1996).

Alpine Lake Productivity

Alpine lakes tend to be ultraoligotrophic, with limited primary production. Primary productivity provides a food supply for zooplankton, which, in turn, provides a food base for trout. The factors that limit productivity in an alpine lake eventually limit growth rates of trout.

Elevation, temperature, flushing rate, stratification, depth and available nutrients interact to affect productivity. However, available nutrients and extended ice cover are usually the limiting factors in the Absaroka-Beartooth (A-B) lakes (Wells 1986; Angelo 1989). Recycling provides the major source of nutrients for alpine lakes (Angelo 1989), although nutrients are available from outside sources (Wells 1986).

Limiting nutrient concentrations in alpine lakes tend to be either available nitrogen (Angelo 1989) or phosphorus (Arneson 1969). In some cases, a colimitation between both nutrients is evident (Dodds and Priscu 1990). The nitrification process associated with recycling is very temperature dependent (Elfving et al. 1975).

Elevation becomes a factor in productivity through its impact on temperature, duration of ice cover, and amount of allochthonous input from vegetation. Lower elevation lakes have greater allochthonous input (Baron et al. 1991), warmer water temperatures, higher decomposition rates, and usually greater nutrient concentrations.

Most water in A-B comes directly or indirectly from snow and glacial melt, and high flushing rates are common (Wells 1986, Angelo 1989). High flushing rates become a factor by dilution of autochthonous nutrient concentrations. When flushing rates approach doubling rates of phytoplankton, a washout of nutrients and phytoplankton may occur (Goldman et al. 1979).

The depths of lakes become a factor by affecting stratification and mean water temperatures. Stratification of deeper lakes may trap nutrients produced through decay in the profundal zone, reducing productivity except during spring and fall turnovers. Stratification also insulates the hypolimnion, resulting in colder temperatures and a reduction in decomposition and nitrification at the bottom.

Lakes < 9 m deep or < 4.1 ha seldom develop lasting stratification during the summer (Nelson 1988). This results in warmer water temperatures, more decomposition, and a mixing of nutrients within the water column.

If the principal source of lake water is direct snowmelt, water temperature will be colder, and nitrogen concentration higher than in one with its water source from an upstream lake. Lower nitrogen concentrations may result from assimilation of nitrogen by organisms in the lakes above (Angelo 1989).

The limited productivity of alpine lakes makes the biotic community very susceptible to disturbance. Disturbances can be in the form of minerals or sediment imported during runoff, or the introduction of exotic organisms such as fish. Growth of fish in alpine lakes is generally related to available food supplies, which is related to productivity, and fish density. In some alpine lakes, growth rates of trout are low, with no easily identifiable cause (Mike Poore, Montana Fish, Wildlife and Parks personal communication).

Rationale for Present Study

The status of fisheries in alpine lakes has become a concern in recent years as a result of their unique nature. While the presence of cold, clear water would indicate ideal conditions for high densities of trout in lower elevation lakes and streams, the limited productivity and extended ice cover of alpine lakes significantly lowers their carrying capacity.

Studies have been done on growth rates of rainbow trout stocked in alpine lakes in Colorado (Nelson 1987, Nelson 1988), and on self-sustaining populations of brook trout in alpine lakes of Wyoming (Chamberlain and Hubert 1996). The number of alpine lakes in the A-B Wilderness provides an excellent cross section for comparison to past and future studies. Factors affecting growth rates of Yellowstone cutthroat trout in alpine lakes have yet to be addressed, and the unique nature of the put-grow-and-take fishery found in the A-B Wilderness can add to our knowledge of trout fisheries in alpine lakes.

Stocking densities and stocking cycles for lakes in the A-B Wilderness are varied to provide a variety of opportunities for anglers. Some Absaroka-Beartooth lakes are stocked with fish on a 4 or 6 year cycle to provide a continuous fishery with large numbers of average sized fish. Many of the more remote lakes are stocked on an 8-year cycle assuming that trout die out at 7 years, and provide a year for the zooplankton community to recover. Since cutthroat trout often survive 9 years in alpine lakes, the 8-year cycle should be changed to 10 or 11 years. A few lakes are stocked at a low density to promote growth of the trout for a "trophy" fishery.

Trout stocked in alpine lakes may not grow well, even at low stocking densities, or growth rates may be good initially, but decline with subsequent plants (Poore and Marcuson 1991). Since growth of fish

is important to a put-grow-and-take fishery, a better understanding of factors affecting growth rates is needed.

For this study, Kookoo Lake and Triangle Lake were chosen. While the two lakes are similar in area, depth, and elevation and are located in the same drainage, there has been a marked difference in growth rates. The Yellowstone cutthroat trout initially stocked in Kookoo Lake at a density of 704/ha grew poorly. A subsequent stocking in 1985 at 349/ha, achieved average growth compared to other A-B lakes, but was described as poor in error (Montana Fish, Wildlife and Parks gill net records). Triangle Lake, in the same basin above Kookoo Lake, has produced some very large cutthroat trout at stocking densities around 250/ha.

Research Objectives

The purpose of this study was to determine factors responsible for poor growth of cutthroat in Kookoo Lake and to examine factors related to the variation in growth rates of cutthroat trout in other alpine lakes. This study was an extensive look for factors that may be implicated as affecting growth rates of cutthroat trout in alpine lakes. Objectives were:

- 1) Develop an age-length relationship for cutthroat trout in Absaroka-Beartooth lakes by using historical data.
- 2) Compare growth rates of cutthroat trout for all A-B lakes to initial plants and subsequent plants.
- 3) Correlate growth rates with lake depth, lake area, lake volume, lake elevation, stock density by area, and stock density by volume.
- 4) Compare physiochemical characteristics of Kookoo Lake and

Triangle Lake.

5) Compare biological characteristics of Kookoo Lake and Triangle Lake.

6) Compare past cutthroat trout growth rates from Triangle Lake and Kookoo Lake to means for the age-class in other Absaroka-Beartooth Lakes.

7) Compare growth rates and health of cutthroat trout in Kookoo Lake and Triangle Lake at similar stocking densities.

CHAPTER 2

STUDY AREA

The Absaroka-Beartooth Wilderness consists of approximately 400,000 ha, straddling the border of Montana and Wyoming, and bordering the northeast corner of Yellowstone National Park (Figure 1). The Wilderness encompasses the highest mountains in Montana, with over 1,000 alpine and subalpine lakes occurring within seven major drainages.

The study area is located in an alpine basin, up the West Fork of the Rock Creek, approximately 50 km northwest of Red Lodge, Montana by road and trail (Figure 2). The area is in Carbon County, with locations being T8S, R17, sec. 23AA, and T8S, R17E, sec. 33A for Kookoo Lake and Triangle Lake, respectively. From the trailhead on the West Fork, it is about 13 km to the lakes with the last 2.5 km being a cross-country climb of about 350 m. Kookoo Lake and Triangle Lake are the only lakes of the six located within the Ship Creek Basin that have perennial outlets.

Kookoo Lake and Triangle Lake were chosen because of poor and good growth rates of stocked cutthroat trout, respectively, as well as being similar in surface area, elevation, and depth. Kookoo Lake is the lowest of the six lakes within the basin (Figure 2), and thus has the highest volume of water entering and leaving. Its perennial outlet disappears into boulders preventing downstream migration of fish, while the inlet stream originates within a glacial moraine barring migration upstream. Triangle Lake is the third lake on Ship Creek (Figure 2), and while upstream migration is not possible due to the 10 m drop immediately above the lake, fish could migrate downstream to an unnamed lake before reaching the moraine that blocks further migration (Marcuson 1985).

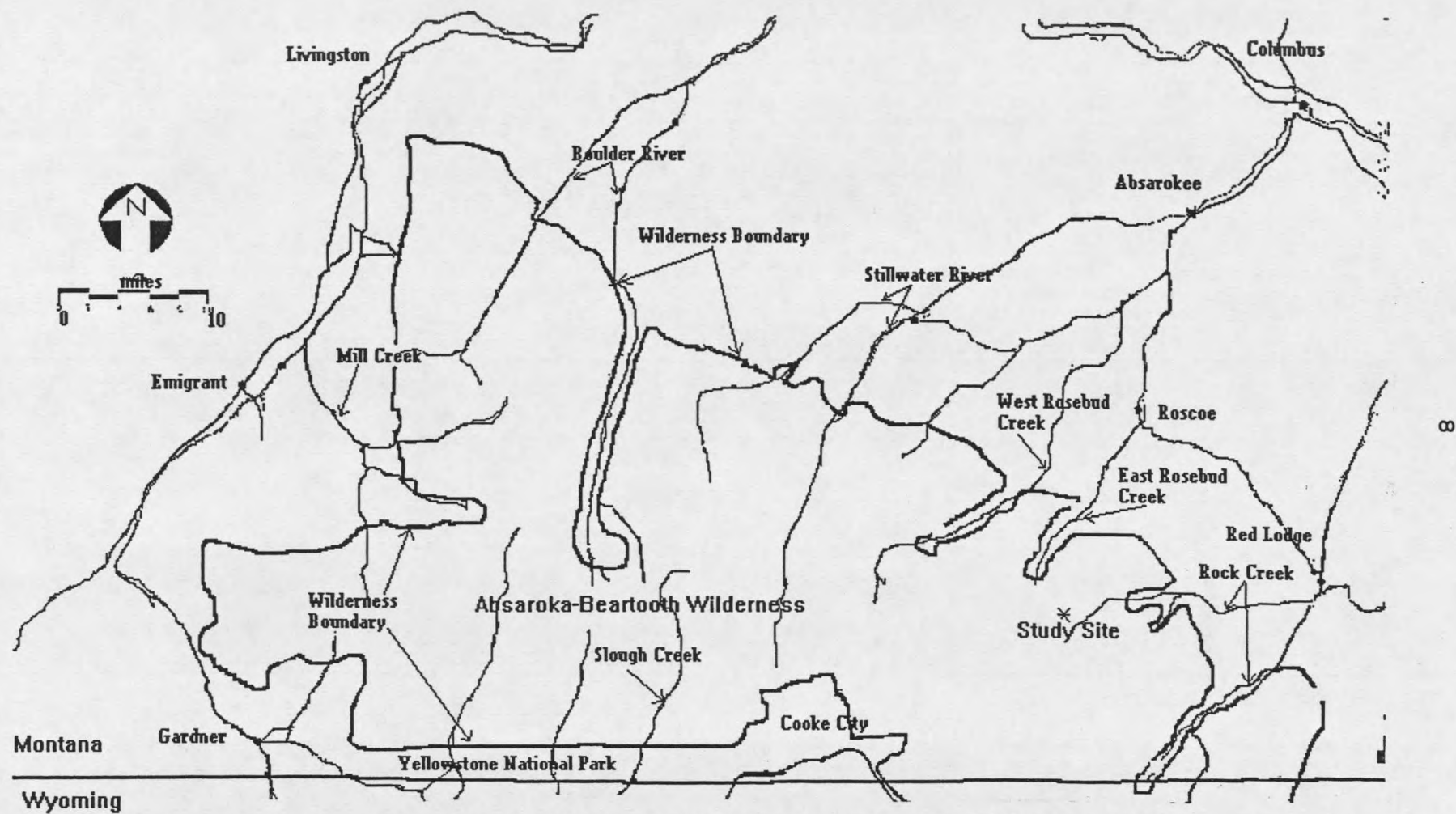


Figure 1. The Absaroka-Beartooth Wilderness, Montana and Wyoming. The study site(*) location is in the Rock Creek drainage, in the eastern portion.

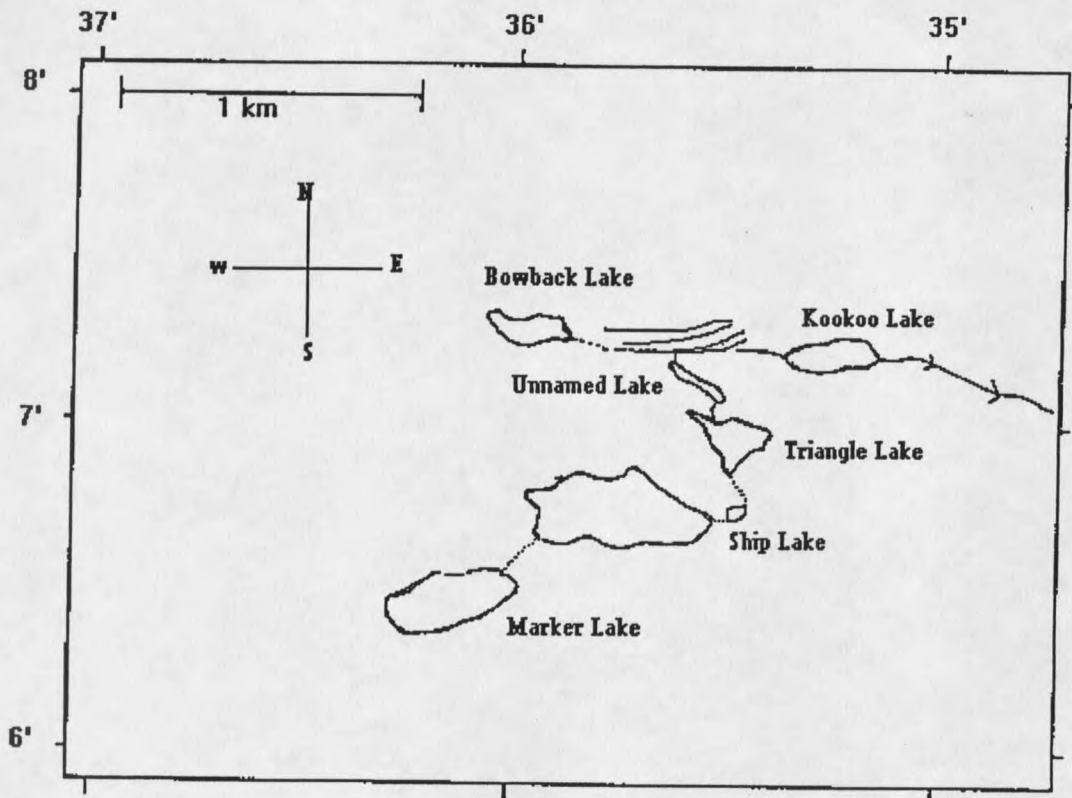


Figure 2. Relative location of lakes within the Ship Creek Basin in the west fork of the Rock Creek drainage. Kookoo Lake is the lowest of the six lakes in the basin.

Kookoo Lake, elevation 3109 m, has an area of 2.47 ha, and a maximum depth of 9.1 m. Comparing these to median values of other A-B lakes (Table 12 Appendix A) it has above average elevation, and has below average area and depth (Table 1).

The shoreline of Kookoo Lake is dominated by grasses and sedges consistent with a *Deschampsia* meadow, and *Carex* bog (Johnson and Billings 1962). North of the inlet, 50 m of shoreline is an assortment of

Table 1. Morphometric characteristics of Kookoo Lake and Triangle Lake (Marcuson 1971, unpublished) with median values for A-B Lakes noted.

	Kookoo Lake	Triangle Lake	Median values for A-B lakes
Location	T8S R17E NE ¼ NE ¼	T8S R17E 23 NW ¼ NE ¼	
Elevation m	3109	3182	2955
Area ha	2.47	2.55	8.8
Maximum length m	229	268	
Maximum width m	108	172	
Maximum depth m	9.1	10.2	11.4
Shoreline length m	636	835	
Volume m ³	78,726	139,544	1,463,333

large boulders, originating from the associated cliff. Southeast of the outlet, a 20 m section of shoreline consists of rounded boulders deposited by glaciation. Located along the northern shoreline are a number of *Salix* thickets. A perennial snow field on the south side of the lake basin provides a constant source of snow melt, supplementing stream flow. Shoreline substrata is a mixture of silt, sand, gravel, rubble, boulders and bedrock.

Triangle Lake is at 3182 m elevation, has a surface area of 2.55 ha, and a maximum depth of 10.2 m (Figure 4). The shoreline on the north and southwest is dominated by bedrock. The cliffs that make up the southwest shore host a perennial snow field that melts directly into the lake. A *Carex* bog is found at the northwest end of the lake. The remainder of the shoreline is formed of small and large boulders deposited by glaciation.

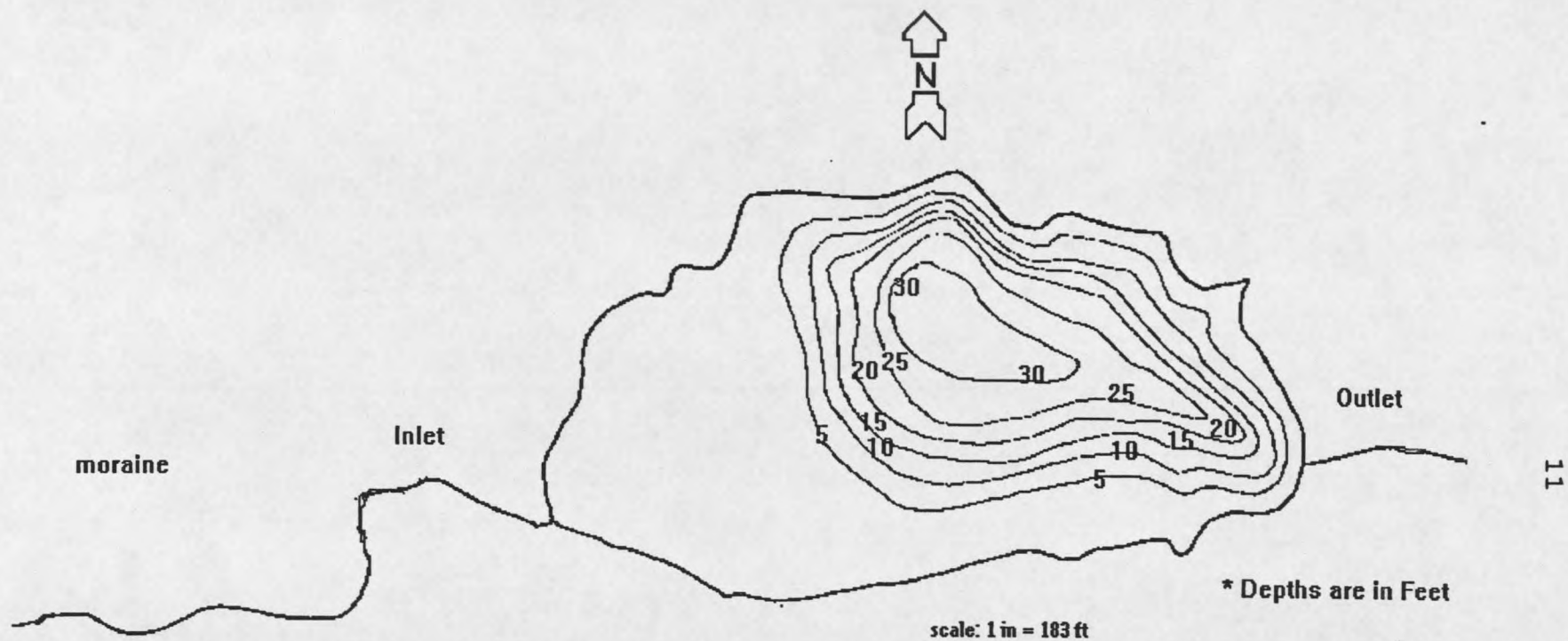


Figure 3. Hypsograph of Kookoo Lake (Pat Marcuson 1971, unpublished).

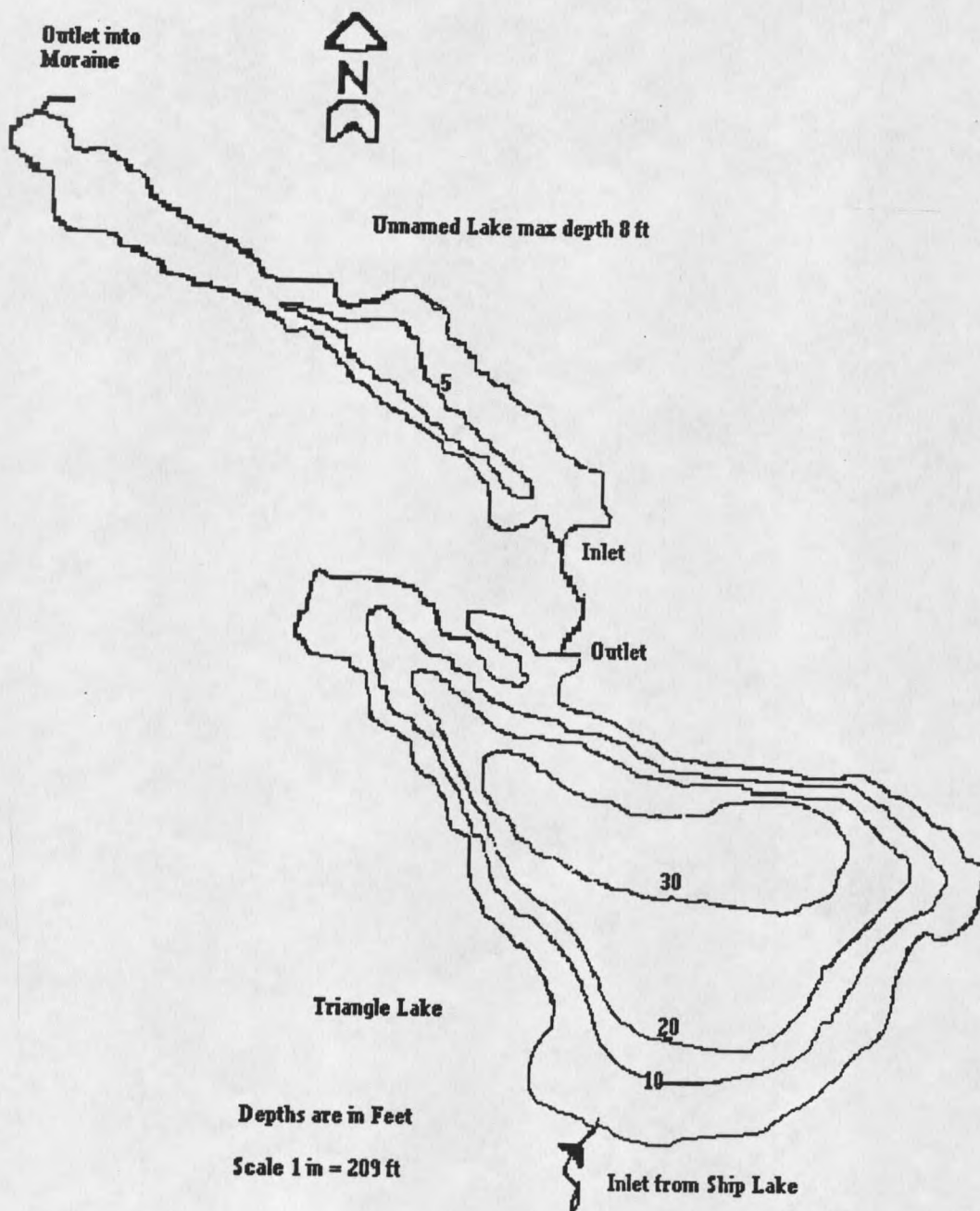


Figure 4. Hypsograph of Triangle and Unnamed Lakes (Pat Marcuson 1971, unpublished).

CHAPTER 3

METHODS

Analysis of Historical Data

By searching the Montana FWP database for the Absaroka-Beartooth Wilderness lakes I found 71 lakes that have not established self-sustaining populations of cutthroat trout following stocking. Ages of fish sampled in these lakes can be determined by the time since stocking. Depth, size and elevation of all 71 lakes were available in the database (Appendix A Table 11). Volume of each was calculated using the volume of a cone (Nelson 1987). The management plans for each drainage were searched for stocking dates and densities. Files at the Fish, Wildlife and Parks office in Billings and Columbus were then searched for available gillnet sampling data.

Fish not of a size consistent with the age class of the plant being assessed were excluded as the result of minimal spawning success. Growth rates for each age class were converted into units of standard deviation using the following equation (Jim Robison-Cox, Montana State University personal communication):

$$\frac{(\text{mean size of fish from sampling of a lake}) - (\text{mean size for age class})}{\text{standard deviation in size for age class}}$$

I standardized elevation, depth, area, volume, stocking density by area, and stocking density by volume by also converting values into units of standard deviation, using the following equation:

$$\frac{V-M}{\text{stdv}}$$

Where

V = value for parameter for individual lake

M = mean for parameter for all lakes

stdv = standard deviation for parameter for all lakes

Initial and subsequent stockings were assigned values of 1 and 2 respectively.

I analyzed the importance of elevation, area, lake depth, lake volume, stocking sequence, stocking density by area, and stocking density by volume by stepwise multiple linear regression, using the IBM student version of "Minitab" (McKenzie et al. 1995). Following the analysis of all lakes, lakes were grouped into those above and below the median for volume ($43.9 \times 10,000 \text{ m}^3$), and a multiple linear regression was also used to assess each group for differences in correlation. A third assessment was conducted grouping samples from initial introductions and all subsequent stockings.

Following analysis of all seven variables, those with p values > 0.05 were removed, and a multiple regression was run with the remaining factors. This was repeated for high and low volume groups, and again with groups from initial and subsequent stockings.

Because of the high variation, and the large number of factors influencing fish growth rates, I developed a second method to examine trends. Lakes were divided into two groups for each factor: those lakes above the median for that factor, and those lakes below the median. The percentage of lakes within each group exhibiting below average growth was then calculated. A H_0 hypothesis that there would be no difference in growth rates in each group was tested. If the parameter had no influence, approximately 50% of the lakes would show above average growth and 50% below average growth. A chi-square test was then conducted on the results.

Assessment of Lake Physical Parameters

Discharge and Flushing

To examine the possibility that flushing of the lakes was a factor in productivity, I measured stream flow at the outlets of the two study lakes using a Montedoro-Whitney Model PS-3 flow meter during the last

week of June, July and August of 1993 and 1994 following standard methods (Robins and Crawford 1954). Volume of the two study lakes was calculated using bathymetric data produced by Pat Marcuson (unpublished) in 1971 (Figures 3 and 4). I calculated theoretical lake flushing rate using the discharge and the volume measurements. (Measurements were difficult during low flows due to the nature of the substrate.)

Water Column Transparency

A standard 20-cm black and white Secchi disc was used to calculate water clarity three times during 1993 and 1994. Measurements were taken between 1200 and 1400. The extinction coefficient was calculated by the equation (French et al. 1979):

$$\frac{1.7}{SD} = n_t$$

Where:

1.7 = a constant

SD = mean Secchi disc depth (m)

n_t = extinction coefficient per m

Assessment of Lake Chemical Parameters

Timing and Common Methods

Water and plankton sampling was conducted during the last week of June, July and August for 1993 and 1994. The lake was accessed using a 2-person vinyl raft. Water samples were taken at 1 m depth intervals using a 2 L Kemmerer bottle, in the deepest portion of the lake. These were immediately placed in 300 mL nalgene bottles, and pH was measured using a Hanna pH/temperature meter. A 250 mL water sample from each depth was then filtered into acid washed 300 mL bottles for further testing, using a Gelman filter funnel with GF-C filters attached to a modified bell-jar. Filters were saved for chlorophyll-a analysis.

Temperature and Dissolved Oxygen

Temperature and dissolved oxygen were measured at 1 m depth intervals in the deepest part of the lake using a calibrated YSI model 57 dissolved oxygen meter coupled to a YSI combination thermistor/O₂ probe. The meter was calibrated at saturation on the surface for the temperature and altitude. On days when battery charge made temperature measurements impossible with the YSI meter, I immediately took water temperature from the Kemmerer bottle water sample using a Hanna pH/temperature meter. The meter was calibrated against saturation values for the surface of the lakes.

In July of 1994, oxygen profiles were taken every 4 h over a 24 h period to calculate oxygen flux due to biological activity within the lakes. Total DO production due to photosynthesis within the lakes was calculated using methods modified from Priscu and Verduin(1994). Values from the two depth profiles showing the greatest difference were subtracted, and these values multiplied by the volume at each depth. Mean changes in mg/L.h for the lakes were calculated from the sum of these values.

pH Measurements

A profile for pH was established using a Hanna pH/temperature meter, following methods outlined earlier. The meter was calibrated using test solutions of pH 4 and pH 7 in the field. In August of 1998, the meter would not fully calibrate, resulting in questionably high pH values.

In July of 1994 profiles were taken every 4 h over a 24 h period to calculate CO₂ flux due to biological activity within the lakes. Diel fluctuation in pH was used to calculate changes in CO₂ concentration by modifying methods outlined by Priscu and Verduin(1994). Instead of titrating in the field to establish a correlation of change in pH per

micromole of acid, a solution corresponding to the alkalinity of each lake was created in the lab at Little Big Horn College. These solutions were created using distilled water and CaCO_3 , and then titrated with an acid solution.

Values from the two depth profiles showing the greatest difference in pH were subtracted, and changes in pH were converted into mg/L of CO_2 . Values for CO_2 were multiplied by the volume at each depth and mean changes in mg/L.h for the lakes were calculated from the sum of these values.

Conductivity

Conductivity was measured at 1 m intervals in the deepest portion of the lake during the last week of June, July and August of 1993, but was eliminated from the study in 1994, as it is related to alkalinity (Table 12, Appendix B), and provided no additional information.

Heavy Metal Concentrations

Water samples were taken from each lake, near the outlet, to test for heavy metal concentrations the last week of June, July and August of 1993. Samples were filtered using Gelman GF-C filters, a hand pump and a 500 mL suction flask. Contents were then placed in 300 mL sample bottles and immediately stabilized with HNO_3 . Samples were then transported to Energy Labs Inc. of Billings, MT, to be analyzed for heavy metals using standard EPA methodology. Constituents tested for were K, Mg, Ar, Ba, Cd, Cr, Cu, Fe, Pb, Mn, Hg, Ni, and Se.

Alkalinity and Hardness

Alkalinity was tested, at the outlets of the two study lakes, using a Hach Limnology Field Kit during the last week of June, July and August of 1993 and 1994. Hardness testing was conducted in 1993 but not

in 1994 (Table 12, Appendix B) since it is related to alkalinity, and provided no additional information.

Available Nutrients, Nitrogen and Phosphorus

Nutrient profiles were established at 1-m depth intervals from the deepest portion of the lake using water samples obtained as noted previously. In 1993, filtered samples were tested for available nitrogen as mg/L NO_3^- , soluble reactive phosphorus as mg/L PO_4^{3-} , and ammonia as mg/L NH_3 using a Hach Field Kit, and a Hach DR2000 spectrophotometer.

In 1994 water samples were obtained as noted previously, but samples were then packed in snow, placed in a cooler, transported to Billings, and frozen, pending analysis of available nitrogen, SRP and ammonia, in Dr. John Priscu's lab at Montana State University, in Bozeman.

Total amounts of available nutrients were calculated by multiplying the concentrations by the volume at each depth, and summing these results. Nitrogen:phosphorus atom ratios were then calculated for each sample date, noting that a balanced ratio would be 16:1 (Redfield 1963).

Assessment of Biological Parameters

Chlorophyll-a Concentrations

Chlorophyll-a profiles were made using the GF-C filters from the water samples taken at 1 m intervals. Filters were immediately wrapped in aluminum foil, and packed in snow for chlorophyll-a analysis. Samples were packed out and frozen, pending analysis in the Little Big Horn College lab.

I conducted analysis of chlorophyll-a concentrations using a Hach DR2000 digital spectrophotometer and methods outlined by

Vollenweider(1971). Extinction values were established at a wavelength of 665 millimicrons, measuring against a 90% acetone blank.

Chlorophyll-a concentrations were then calculated using the following formula(Wells 1986, and Golterman & Clymo 1971):

$$\text{Chl-a} = \frac{12D_{665}VeF}{VwL}$$

Where:

Chl-a = Chlorophyll-a in mg/m³

D₆₆₅ = optical density at wavelength 665 millimicrons

Ve = volume of the extract in liters

F = 1000 micrograms/mg

Vw = volume of the water sample in liters

L = length of light path in the spectrophotometer cell(cm)

Benthos

Sampling of benthos was conducted during the last week of June, July and August in 1993. Samples were taken from the substrate in the deepest portion of the lake using an Eckman Dredge. A 290 mL sample was placed in 300 mL nalgene bottles and fixed using approximately 5 mL of 4-6% formalin. Samples were screened in the lab at Little Big Horn College, and organisms were counted and identified to Order(Table 13 Appendix C).

Zooplankton

Zooplankton samples were taken during the last week of June, July and August in 1993 and 1994. Two vertical plankton tows were made with a Wisconsin net, in the deepest portion of the lake(9 m), and rinsed into a single 300 mL nalgene bottle. Samples were fixed with 5 mL of 4-6% formalin in the field, and transported back to Billings for analysis. Samples were counted using counting wheels and dissecting scopes, and identified to Order. Concentrations of each type of organism were

calculated knowing the volume of water filtered for the two plankton tows.

Fish Growth and Health

Kookoo Lake and Triangle Lake were gillnetted in 1993 and 1994 to remove remnant trout from previous stockings. Young-of-the-year Yellowstone cutthroat trout were fin-clipped at the Montana Department of Fish, Wildlife and Parks Hatchery in Big Timber, Montana. Those intended for Kookoo Lake and Triangle Lake had the left pectoral fin and right pectoral fin removed respectively. This would allow me to identify fish from marginal reproductive efforts, and identify fish that had migrated. Fish were stocked by helicopter at a density of 244/ha in Kookoo Lake, and 242/ha in Triangle Lake.

Fish were gillnetted in June of 1995 and June and September of 1996, to monitor growth and health. Fish were measured for maximum length(cm), weighed(g), and subjected to HAI fish health analysis according to methods modified from Adams et al. (1993), with blood work excluded. Twenty-one other lakes with trout populations were subjected to HAI assessment(Adams et al. 1993) as a reference for Kookoo Lake.

CHAPTER 4

RESULTS

Analysis of Historical Data

Seventy-one lakes have been or currently are stocked with Yellowstone cutthroat trout, and support little or no natural reproduction (Table 11 Appendix A). There were 248 gillnet records from these lakes covering the period of 1956-1997. Mean cutthroat trout lengths from each sample were used to calculate average lengths for each age-class. Most samples were of fish from age 2 to 7, leaving small sample sizes for ages 1, 8, 9 and 10 (Table 2, Figure 5).

Table 2. Age-length means, medians and standard deviations for cutthroat trout in Absaroka-Beartooth lakes 1956-1997.

Age	n=	Mean	Median	Stdv	Variation
1	17	19.0 cm	17.5 cm	12.1 cm	25.9 cm
2	36	24.7 cm	24.4 cm	14.4 cm	35.0 cm
3	35	28.5 cm	28.4 cm	17.8 cm	39.0 cm
4	33	31.2 cm	30.7 cm	19.8 cm	42.5 cm
5	28	32.4 cm	31.8 cm	23.2 cm	41.6 cm
6	27	33.2 cm	32.5 cm	23.9 cm	42.5 cm
7	36	34.5 cm	34.2 cm	25.2 cm	43.9 cm
8	14	37.8 cm	37.5 cm	25.3 cm	50.2 cm
9	16	37.2 cm	37.1 cm	24.6 cm	49.8 cm
10	6	40.8 cm	39.8 cm	26.8 cm	54.9 cm

Stdv = standard deviation

Cutthroat Trout Growth Rates in Kookoo Lake and Triangle Lake

The first stocking of cutthroat trout in Kookoo Lake at a density of 704/ha resulted in below average annual growth rates compared to 71 other Absaroka-Beartooth lakes (average stocking density 385/ha). The second stocking at 345/ha resulted in average growth, as did the third stocking at 244/ha (Figure 6, Table 14 Appendix D).

There was no sampling record for the first stocking of cutthroat trout in Triangle Lake. The second stocking at a density of 242/ha

produced fish that showed below average growth for their first year, average growth for the second year, and above average growth thereafter. The third stocking exhibited above average growth throughout their duration in the lake (Figure 7, Table 15 Appendix D).

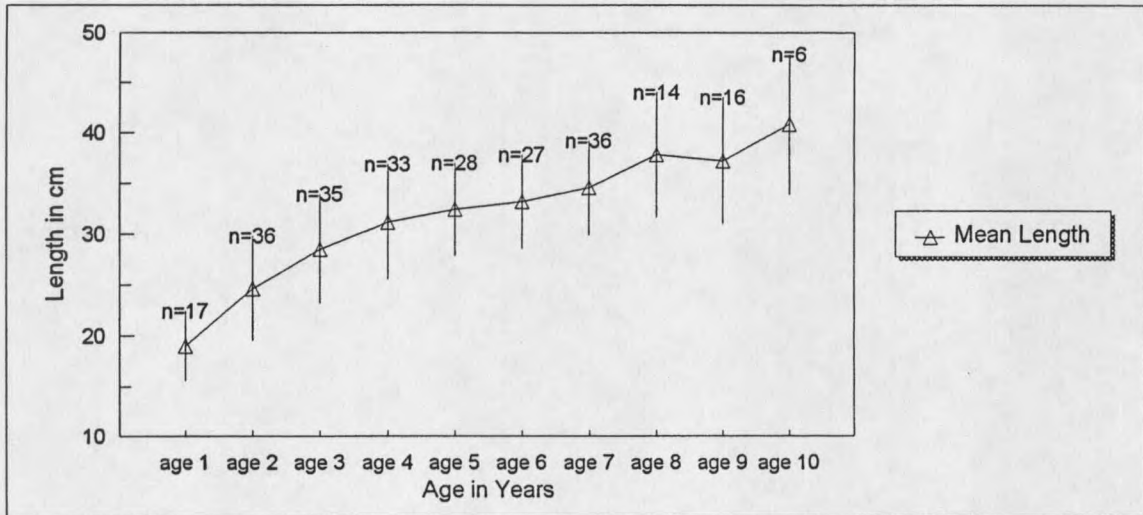


Figure 5. Mean length, plus and minus one standard deviation, of cutthroat trout in the Absaroka-Beartooth Wilderness lakes, by age-class 1956-1997.

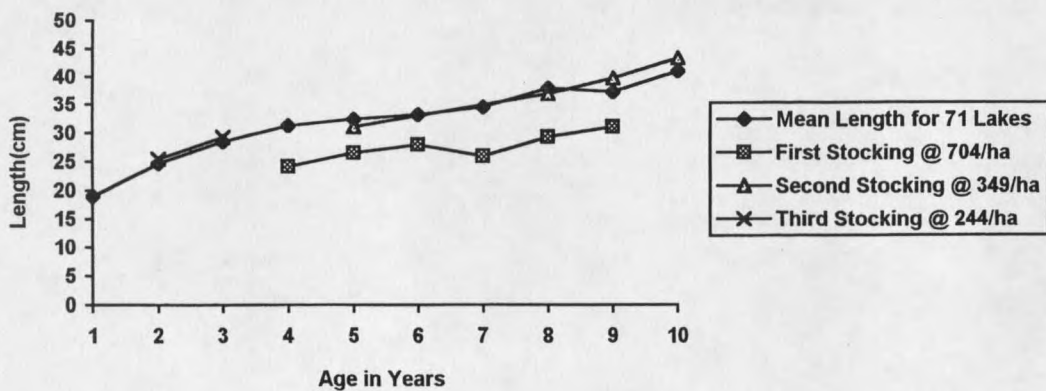


Figure 6. Comparison of growth in length of cutthroat trout in Kookoo Lake, at three stocking densities, to the mean for 71 other Absaroka-Beartooth Lakes.

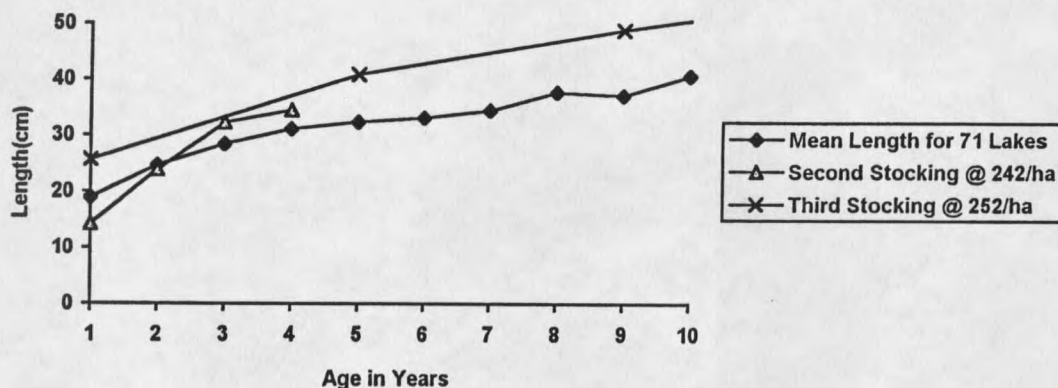


Figure 7. Comparison of growth in length of cutthroat trout in Triangle Lake, at two stocking densities, to the mean for 71 other Absaroka-Beartooth Lakes.

Factors Affecting Growth Rates

Mean lengths of cutthroat trout from first-time stockings in 71 lakes were slightly (not significantly) larger than subsequent stockings, even though initial stocking densities averaged 49% higher than the mean stocking density for subsequent introductions (Figure 8). The impact of stocking sequence was verified statistically in analysis of high volume lakes ($p=0.026$) where growth rates correlated negatively.

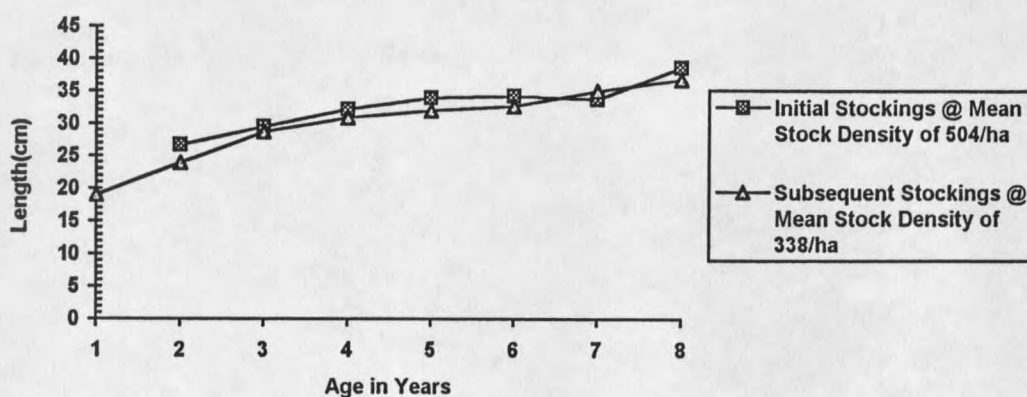


Figure 8. Growth of cutthroat trout from initial plants in A-B Lakes compared to subsequent stockings.

Stepwise multiple regression of the importance of elevation, depth, area, volume, stocking sequence (initial stocking vs subsequent), stock density by area, and stock density by volume accounted for 9.9% of the variation in growth rates, but depth, area, and volume had insignificant correlations $p > 0.6$ (Table 3 and Table 4). Elevation, stock density by area, and stock density by volume had significant correlations $p < 0.01$ (Table 3).

Table 3. Correlation of seven factors that may affect the growth of cutthroat trout in alpine lakes in the A-B Wilderness, using stepwise multiple linear regression.

Predictor	Coefficient	p
Elevation	-.04948	.008
Depth	-.03256	.665
Area	-.00507	.835
Volume	+.03807	.667
Stock sequence	-.00906	.812
Fish per hectare	-.09271	.007
Fish per hectare*meter	+.10394	.007

$r^2 = 9.9\%$

A multiple linear regression of the latter three factors accounted for 9.8% of the variation in growth. In both cases elevation ($p = 0.007$), and stock density by area ($p = 0.003$) had negative correlations with growth, while stock density by volume was positively correlated with growth ($p = 0.002$). This positive correlation with stocking density by volume was an artifact of the poorer growth noted in high volume lakes, and this disappeared when lakes were grouped in as high and low volume lakes and assessed separately.

Growth rates from subsequent introductions were positively correlated with stocking density by volume ($p = 0.004$), and negatively correlated with elevation ($p = 0.01$), and stock density by area ($p = 0.007$) (Table 4).

Growth rates in lakes less than the median volume (1,463,333 m³) correlated negatively with elevation ($p = 0.006$). Growth rates in lakes

Table 4. Multiple linear regression of factors that significantly correlate with the growth of cutthroat trout in alpine lakes in the A-B Wilderness.

Sample	Elevation	Area	Depth	Volume	Stocking sequence	Density by area	Density by volume	'r' ²
All lakes	cc=-0.050 p=0.007					cc=-0.089 p=0.003	cc=+0.010 p=0.002	9.8%
Subsequent plants	cc=-0.050 p=0.010					cc=-0.109 p=0.007	cc=+0.138 p=0.004	12.6%
Low volume lakes	cc=-0.071 p=0.006							15.8%
High volume lakes					cc=-0.101 p=0.026	cc=-0.093 p=0.009		7.9%
cc=correlation coefficient								

larger than the median correlated negatively with stocking sequence ($p=0.026$) and stocking density by area ($p=0.009$) (Table 4).

The negative correlation with stocking density by area seems to have the largest effect on growth rates using stepwise multiple regression of five different groupings of the data set. A strong negative correlation was also noted for elevation in most data sets. Stocking sequence strongly correlated negatively with growth in the high volume lake data set.

When stocking density in A-B lakes by area was examined for trends, cutthroat trout growth in 63% of lakes with stocking densities $>311/\text{ha}$ (median stocking density) exhibited below average growth suggesting a negative influence on growth ($p=0.042$ chi-square test). Of the lakes with stocking densities less than $311/\text{ha}$, 47% exhibited below average growth, suggesting little influence (Figure 9, Table 5, Table 16 Appendix E).

When stocking density by volume was examined, 55% of the lakes with below median density ($69/\text{ha}\cdot\text{m}$) showed below average growth compared to 51% of lakes with above average densities, indicating that stocking density by volume had little impact (Figure 9, Table 5, Table 16 Appendix E).

I grouped A-B lakes into those above and those below the median elevation of 2955 m. Cutthroat trout growth was below average in 61% of the higher elevation lakes, compared to 50% of lower elevation lakes (Table 5, Figure 10, Table 16 Appendix E). This approach suggests that higher elevations have a negative influence on cutthroat trout growth ($p=0.61$ chi-square test).

When lakes above and below the median depth of 11.4 m were examined, growth was below average in 62% of the deeper lakes, compared to 47% of the shallower lakes (Table 5, Figure 10, Table 16 Appendix E). This indicates that deeper lakes have a negative effect on growth ($p=.047$).

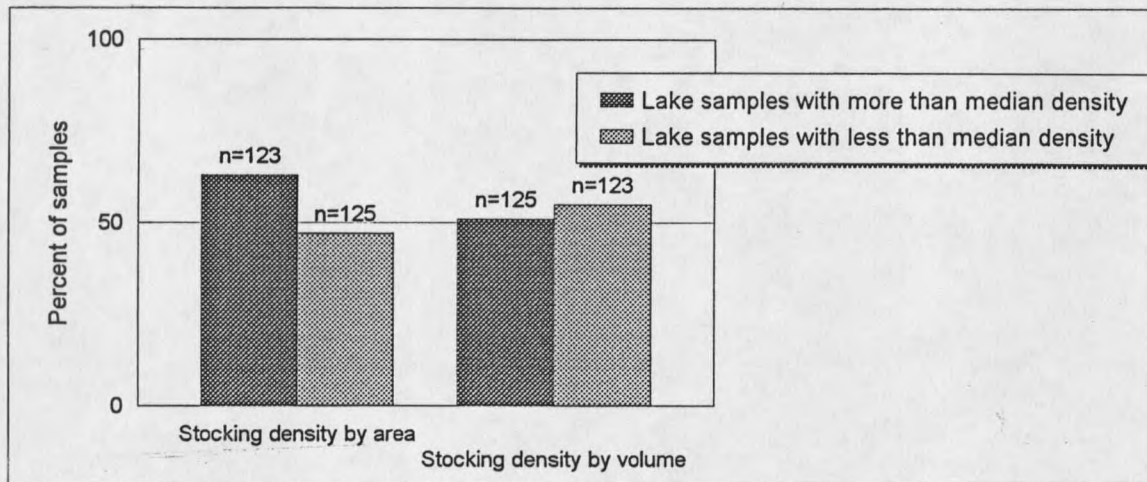


Figure 9. Percentage of lake samples with below average growth of cutthroat trout, comparing lakes with stocking densities higher and lower than the median density for all samples.

Table 5. Percent of lakes with below average growth of cutthroat trout, comparing lakes above and below the median for each parameter.

	Stock density by area	Stock density by volume	Elevation	Depth	Volume	Area
Median value	311/ha	69/ha.m	2955 m	11.4 m	43.9 ha*m	8.8 ha
>Median	63% n=123	51% n=125	61% n=146	62% n=128	56% n=131	58% n=139
Trend	-	None	-	-	-	-
Chi-square	p=0.042		P=0.061	p=0.047	p=0.189	p=0.115
<Median	47% n=125	55% n=123	50% n=102	47% n=120	49% n=117	53% n=109
Trend	None	None	none	none	none	None

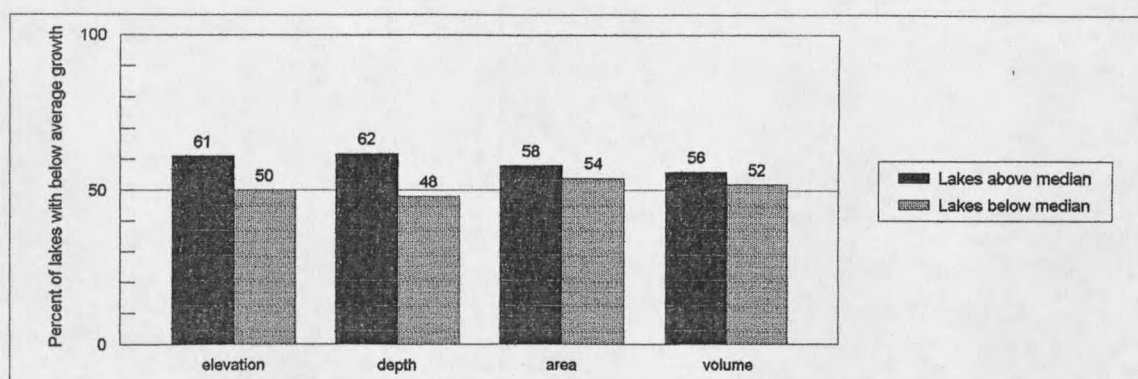


Figure 10. Percentage of lake samples with below average growth of cutthroat trout, comparing samples from lakes above and below the median values for all A-B Lakes.

chi-square test). A similar trend was seen when comparing lake volume and area, and this may be because depth, area and volume are interrelated.

Similar, though not identical, results were noted when trend analysis and multiple regression were compared. Depth correlated negatively with growth in the trend analysis, but was not supported by multiple regression. Stocking density and elevation correlated negatively using both approaches (Table 6).

Table 6. Comparison of trend and statistical analysis of various physical characteristics, and stocking on the growth rates of cutthroat trout in alpine lakes of the A-B Wilderness.

Parameter	Trend correlation	Correlation coefficient	P	
Depth-trend	-		0.047	
Area -trend	-		0.115	
Volume-trend	-		0.189	
Elevation-trend and stat.	-		0.061	
		-0.050	0.007	supports
Stocking sequence-trend	-			
Stat.-high volume lakes		-0.101	0.026	supports
Stock density by area-all	-	-0.089	0.003	supports
Stock density by volume-all	0	+0.100	0.002	

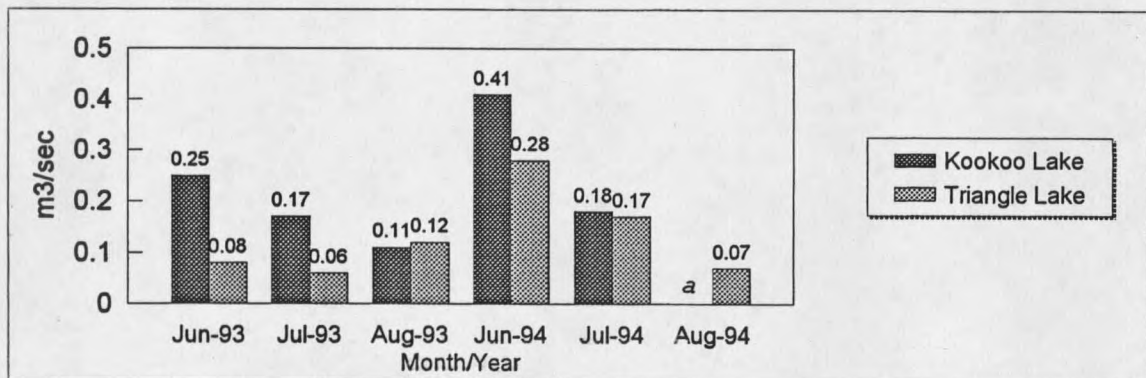
Stocking density by volume showed no trend, but correlated positively with growth when all lake samples were analyzed together.

This was, however, an artifact of poorer growth noted in deeper lakes. No statistically significant correlation was noted for stocking density by volume when lakes were separated into those above and below the median for volume.

Physical Parameters of Kookoo and Triangle Lakes

Discharge and Flushing

Discharge from Kookoo Lake always exceeds Triangle Lake, if data from August are excluded (Figure 11). The effect of higher discharge is magnified by the smaller volume of Kookoo Lake resulting in a flushing rates two to four times faster than Triangle Lake (Figure 12).

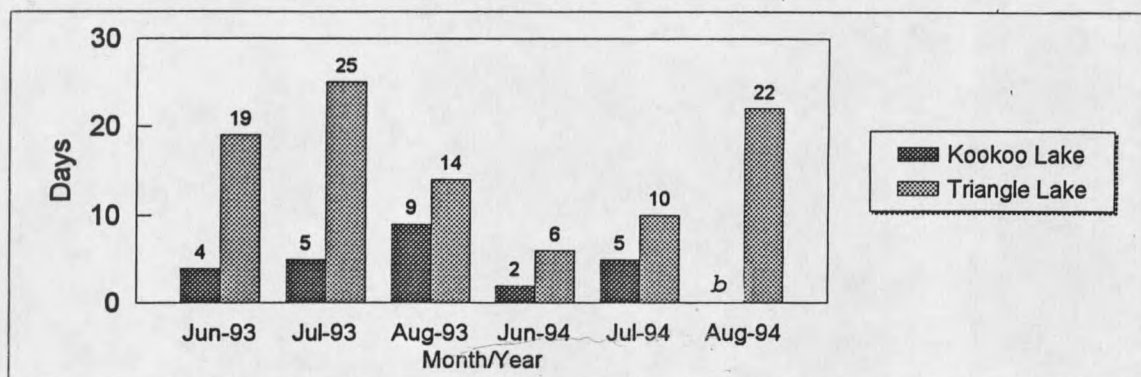


a-substrate prevented measurement during low flow

Figure 11. Discharge from Kookoo Lake and Triangle Lake in m³/sec, June, July and August 1993 and 1994.

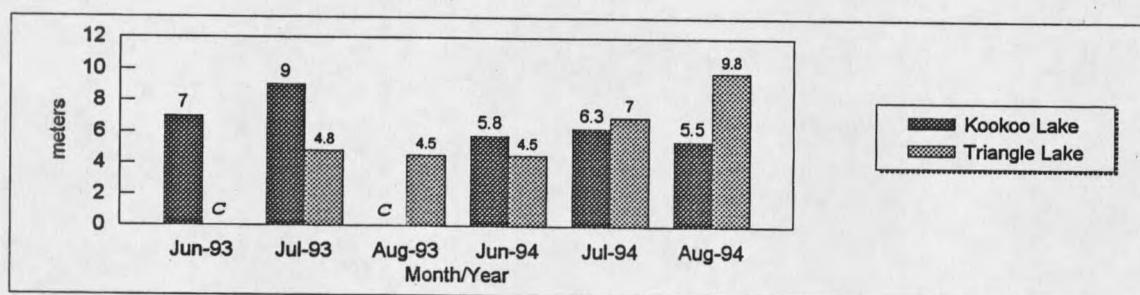
Water Column Transparency

There was no obvious trend in water column transparency although variation in transparency measurements was greater in Triangle Lake where Secchi depth ranged from 4.45 to 9.75 m compared to 5.5 to 9.0 m for Kookoo Lake, during the study (Figure 13, Tables 17 and 18 Appendix F).



b- substrate prevented measurement during low flow

Figure 12. Calculated flushing rates for Kookoo Lake and Triangle Lake in days, June, July and August 1993 and 1994



c-no measurement taken

Figure 13. Secchi depths for Kookoo Lake and Triangle Lake, June, July and August, 1993 and 1994.

Temperature and Dissolved Oxygen

Temperature profiles show that little stratification occurred in either lake during the summer, although winter stratification occurred with the presence of ice cover, as noted in June 1993 samples (Figures 14 and 15). A temporary or diel stratification may result during the

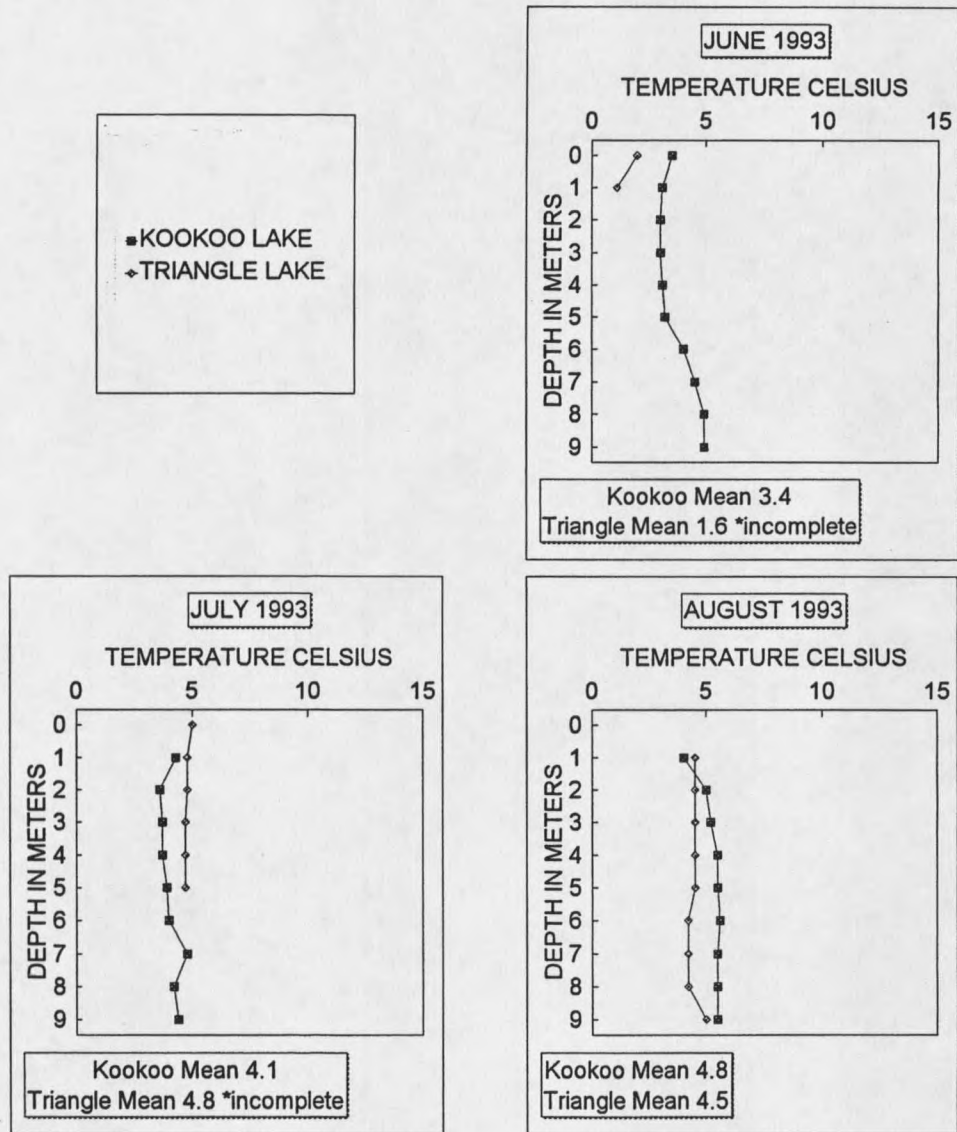


Figure 14. Temperature profiles for Kookoo Lake and Triangle Lake for June, July and August 1993.

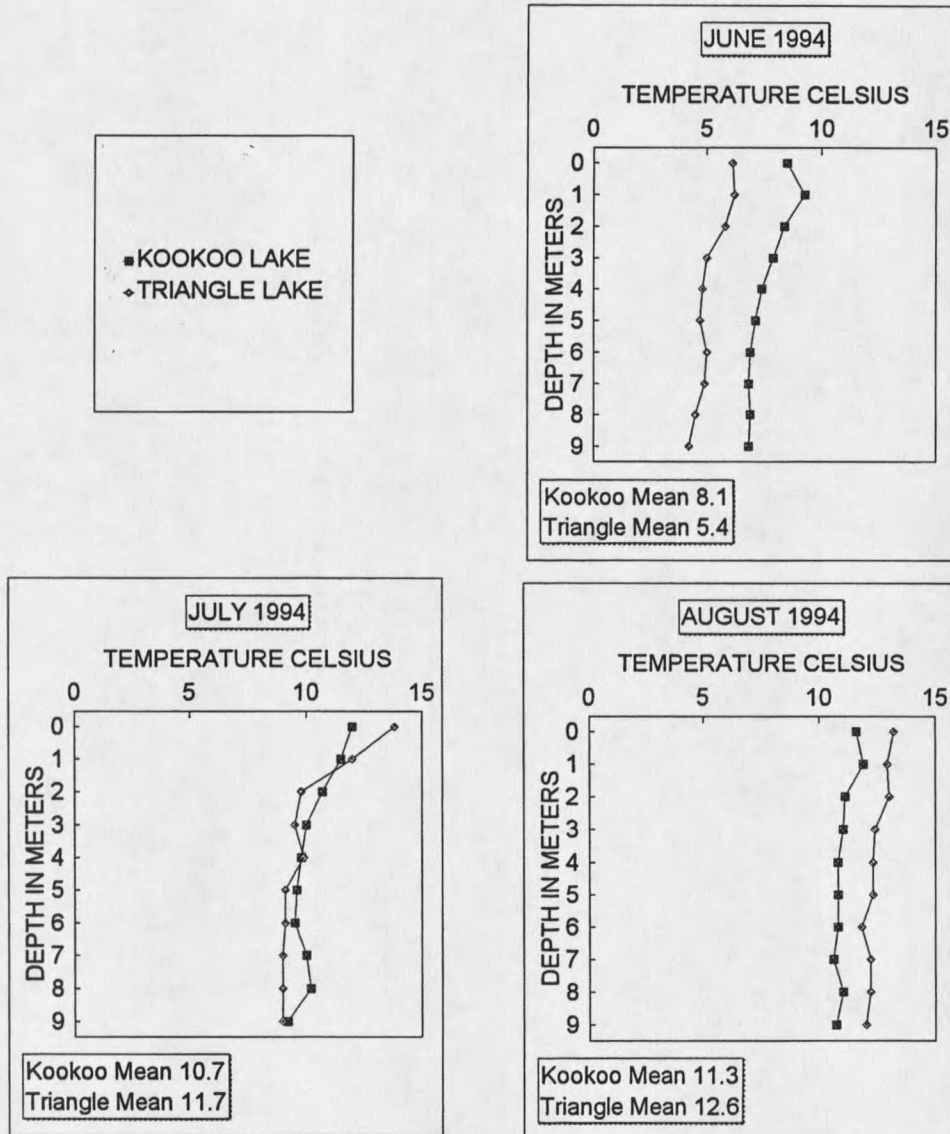


Figure 15. Temperature profiles for Kookoo Lake and Triangle Lake for June, July and August 1994.

warm summer months (Figure 16). Ice cover disappeared first on Kookoo Lake, resulting in warmer water temperatures in June. Water temperatures in July and August are similar although temperatures were lower in Kookoo Lake in July and August of 1994, probably due to the

higher flushing rate, and the colder water imported from Bowback Lake (Figure 2). Water temperatures were markedly different between 1993 and 1994, with 1993 being an atypically cold and wet year, and 1994 being atypically warm and dry.

Due to the lack of stratification, the entire water columns of both lakes warmed uniformly throughout the summer (Figures 14 and 15), allowing nutrient mixing. Mean water temperatures varied from 3.4 to 11.3 C° in Kookoo Lake and 1.5 to 12.6 C° in Triangle Lake. In July of 1994, the mean water temperature fluctuated 2.6 C° in Kookoo Lake and 1.5 C° in Triangle Lake over a 24 h period.

Dissolved oxygen profiles illustrate the presence of winter stratification in June of 1993, and the general lack of stratification throughout the summer (Figures 17 and 18, Tables 19 and 20 Appendix G). Dissolved oxygen levels were low near the substrate due to the oxygen requirements of decomposition. The presence of decomposers and photosynthetic periphyton on the substrate cause a large diel fluctuation in DO (Figure 16, Tables 21 and 22 Appendix H).

pH

The pH of both study lakes rose throughout the summer. The pH of Kookoo Lake rose from a mean of 7.2 in June of 1994 to 8.8 in August (Figure 19, Tables 23 and 24 Appendix I). Triangle Lake experienced a similar rise from 6.9 in June to 8.2 in August.

Diel measurements of pH in July of 1994 (Figure 16, Tables 25 and 26 Appendix J) resulted in larger daily shifts in pH being present in Triangle Lake, indicating more biological activity than in Kookoo Lake. The mean daily change in pH was 0.23 in Kookoo Lake and 0.50 in Triangle Lake.

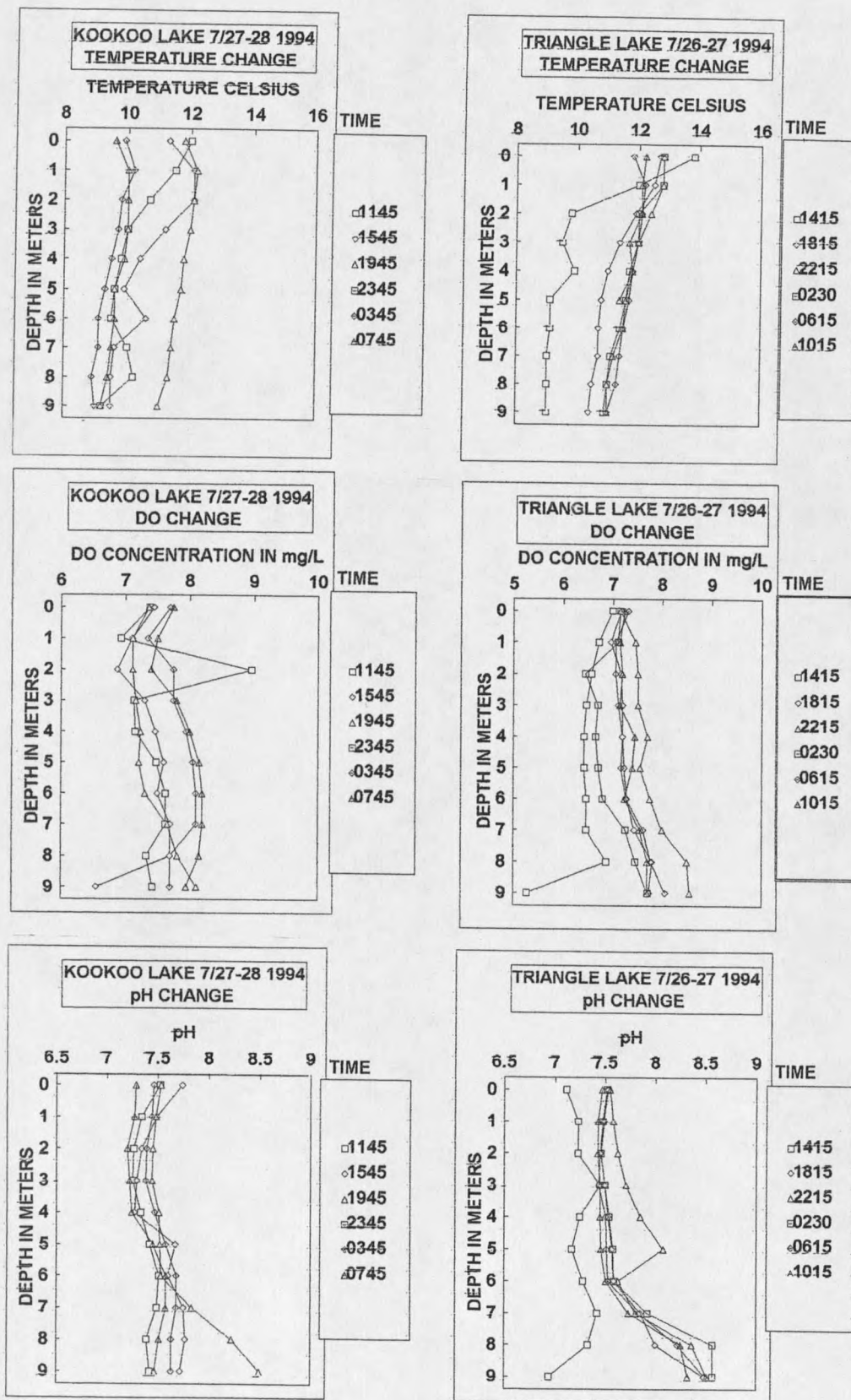


Figure 16. Diel change in temperature, dissolved oxygen and pH profile for Kookoo Lake and Triangle Lake in July of 1994

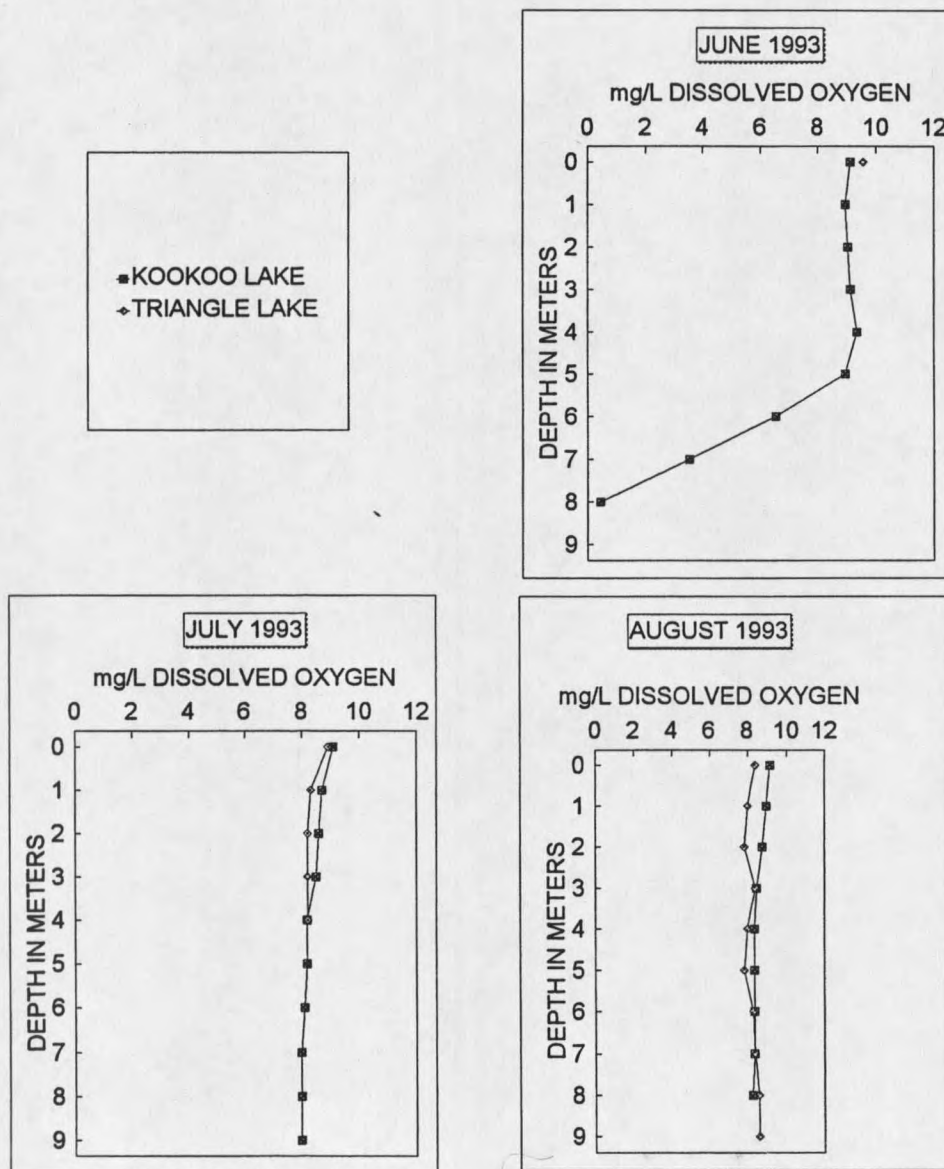


Figure 17. Dissolved oxygen profiles for Kookoo Lake and Triangle Lake for June, July and August 1993.

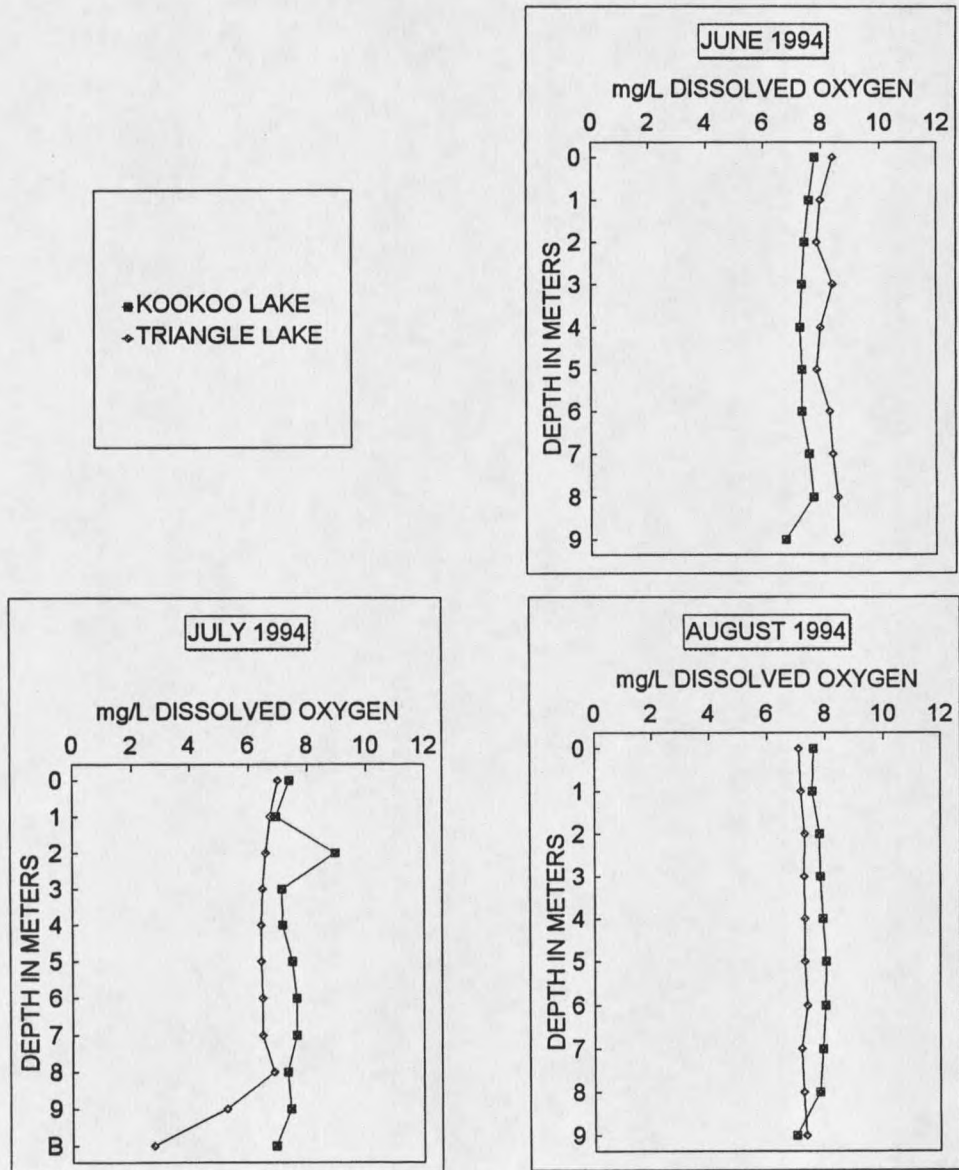


Figure 18. Dissolved oxygen profiles for Kookoo Lake and Triangle Lake for June, July and August 1994.

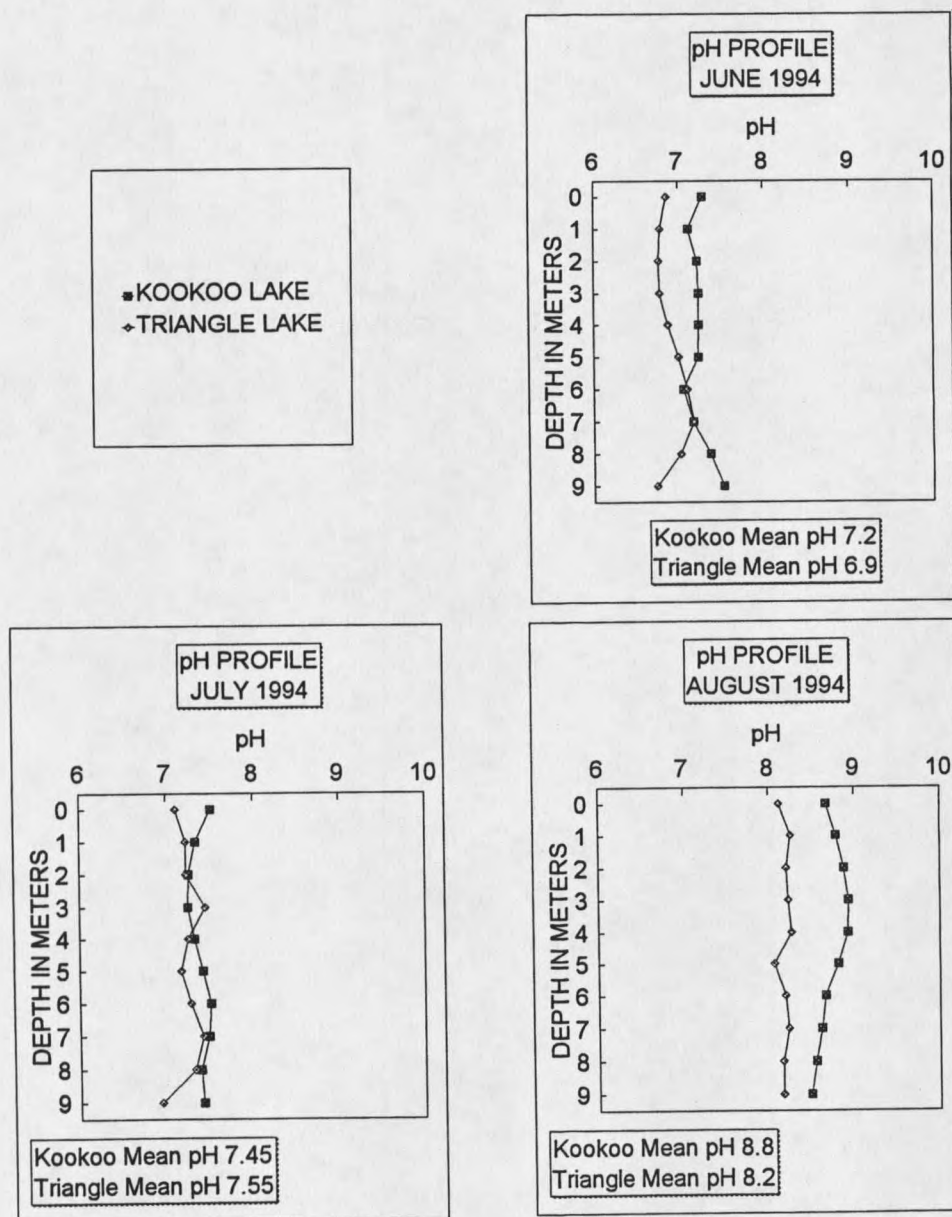


Figure 19. Kookoo and Triangle Lake pH profiles June, July and August 1994. (Aug. values, unable to calibrate meter)

Heavy Metal Concentrations

Most heavy metal concentrations were below detectable levels using standard EPA methods, and those detected were at very low concentrations (Table 7). From these data it is obvious that heavy metal contamination was not a concern.

Table 7. Heavy metal concentrations from Kookoo and Triangle Lakes, using standard EPA methods, June, July and August, 1993. Most samples were below the detectable levels noted. Concentrations, month and locations are noted for detectable values.

Metal	Detection Level	Lake	Concentration	Depth	Date
Arsenic	0.005 mg/L				
Barium	0.1 mg/L				
Cadmium	0.001 mg/L	Kookoo	0.003 mg/L	0 m	8/93
		Triangle	0.003 mg/L	9 m	8/93
Chromium	0.01 mg/L				
Copper	0.01 mg/L				
Iron	0.03 mg/L	Triangle	0.16 mg/L	9 m	6/93
		Triangle	0.10 mg/L	0 m	7/93
Lead	0.01 mg/L				
Magnesium	1.00 mg/L	Triangle	1.00 mg/L	0 m	6/93
		Triangle	1.00 mg/L	9 m	6/93
Manganese	0.01 mg/L	Triangle	0.02 mg/L	0 m	7/93
		Kookoo	0.03 mg/L	9 m	8/93
Mercury	0.001 mg/L				
Nickel	0.01 mg/L	Kookoo	1.00 mg/L	0 m	6/93
Potassium	1.00 mg/L				
Selenium	0.005 mg/L				

Alkalinity

Alkalinity varied widely in 1993 (Table 12 Appendix B), as values were low and glassware was contaminated by being reused in measuring other chemical parameters. Glassware was rinsed a minimum of four times in 1994, with more consistent results. In 1994, values were low for both lakes, but were consistently higher in Kookoo Lake (Figure 20, Table 12 Appendix B).

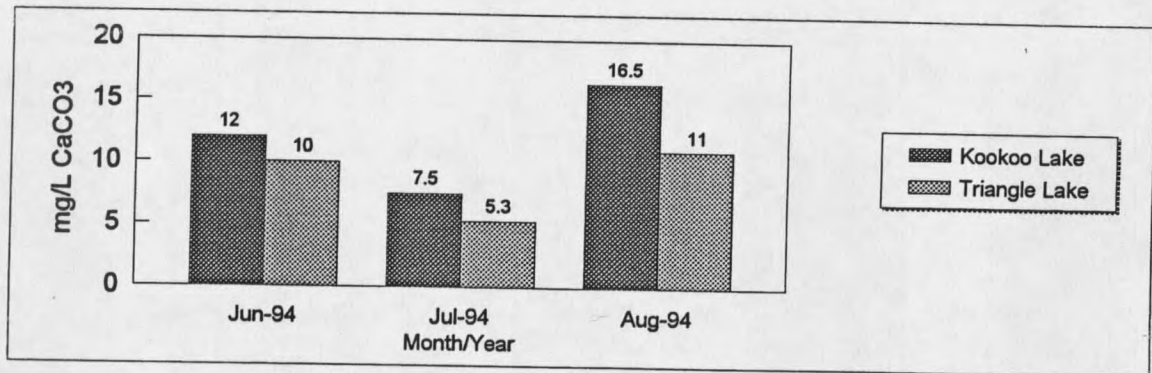


Figure 20. Alkalinity in mg/L CaCO₃ near the surface of Kookoo Lake and Triangle Lake in 1994.

Assessment of Biological Parameters

Chlorophyll-a Concentrations

Mean chlorophyll-a concentrations and profiles of chlorophyll-a concentration were developed to compare productivity within the two study lakes (Figures 21 and 22, Tables 27, 28 and 29 Appendix K).

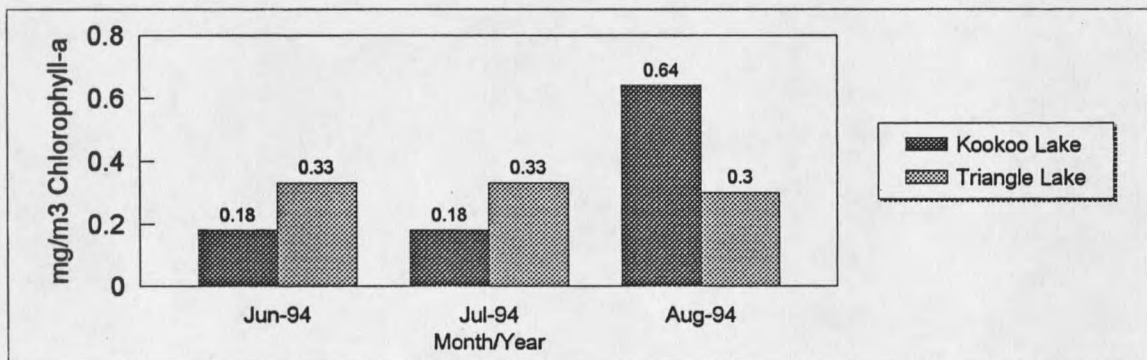


Figure 21. Mean chlorophyll-a concentrations for Kookoo Lake and Triangle Lake in 1994.

It should be noted that Chlorophyll-a concentration is only a measure of the relative standing crop within the lakes, and not actual production. Triangle Lake exhibited higher concentrations of chlorophyll-a during the months of June and July of 1994, than Kookoo Lake. Triangle Lake

chlorophyll-a levels remained relatively constant at around 0.3 mg/m^3 throughout the summer (Figure 21). In August, Kookoo Lake levels more than tripled from 0.18 mg/m^3 to 0.64 mg/m^3 . Both lakes had higher concentrations of chlorophyll near the bottom possibly indicating higher nutrient availability and suitable light penetration to the substrate. Photoinhibition near the surface of alpine lakes has also been noted (Wells 1986), forcing phytoplankton to concentrate at greater depths.

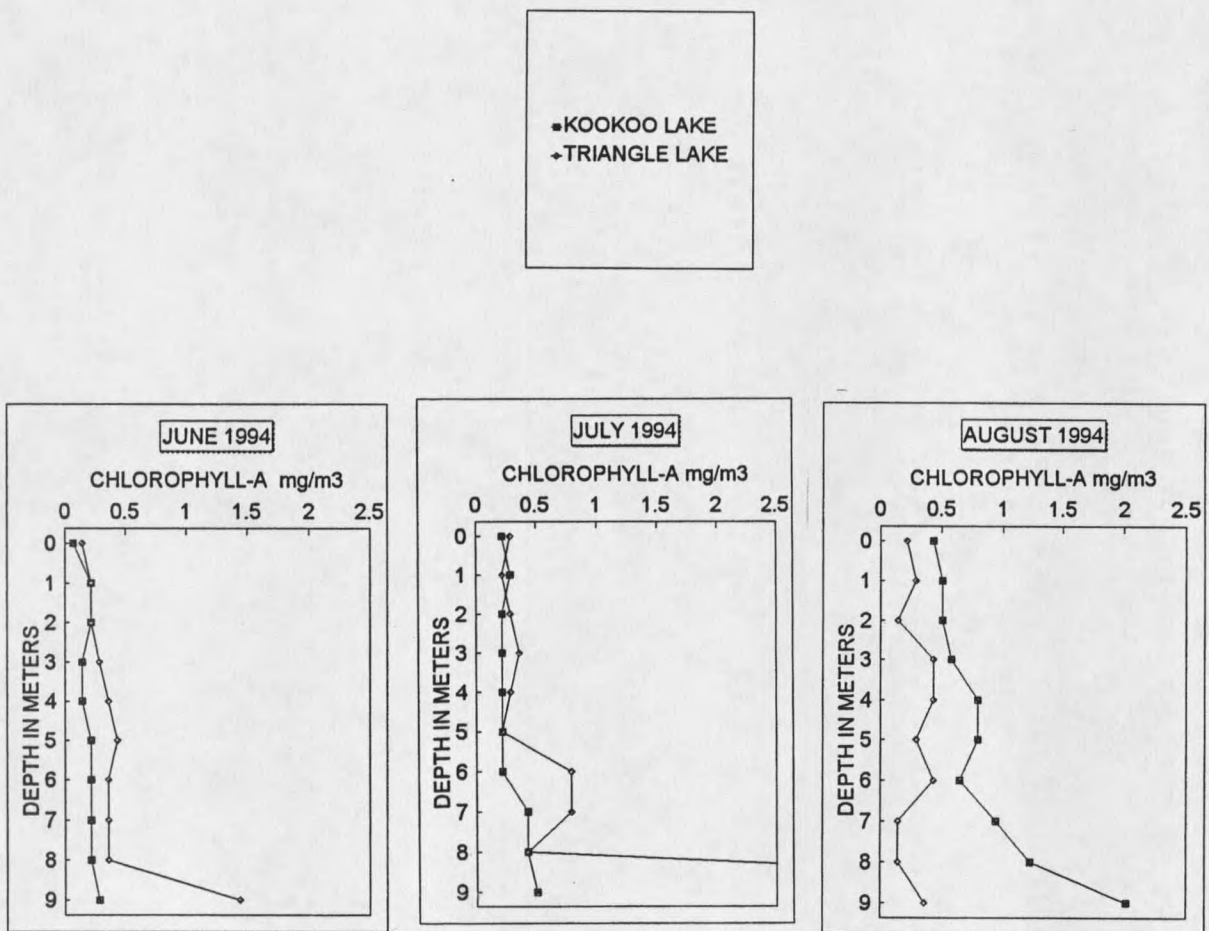


Figure 22. Comparison of Chlorophyll-a profiles for Kookoo Lake and Triangle Lake June, July and August, 1994

Benthos

Samples from June 1993 decomposed prior to counting. All 1994 samples, except one, contained members of the Genus *Chironomas* exclusively. The sole exception included the Order Plecoptera (Table 13 Appendix C).

Zooplankton

Numbers and composition of zooplankton differed markedly in Triangle and Kookoo Lakes (Table 8). The samples were dominated by members of the Orders Cladocera and Copepoda. Triangle Lake had a much higher density of both types of crustaceans (number per m³), and the zooplankton community was dominated by cladocerans. Zooplankton density was much lower in Kookoo Lake, and was dominated by copepods (Figures 23 and 24).

Table 8. Zooplankton density for Kookoo Lake and Triangle Lake in June, July and August, 1993 and 1994.

Lake	Month	#m ³ Cope	#m ³ Clad	#m ³ Chir	#m ³ Oth	#m ³ Total	% Cope	% Clad	% Chir	% Oth
Koo	June	57	3	5	0	65	88	4	8	0
Tri	93									
Koo	July	3	0	0	1	4	83	0	0	17
Tri	93	59	517	2	0	578	10	90	0	0
Koo	Aug	22	4	2	0	28	79	13	8	0
Tri	93	45	55	1	1	102	44	54	1	1
Koo	June									
Tri	94	199	24	2	2	227	88	11	1	1
Koo	July	20	16	0	3	39	51	41	0	8
Tri	94	56	254	0	1	311	18	82	0	0
Koo	Aug	7	10	0	0	17	42	58	0	0
Tri	94	44	365	0	0	409	11	89	0	0

Koo=Kookoo Lake

Tri=Triangle Lake

Clad=Order Cladocera

Cope=Order Copepoda

Chir=Genus Chironomas

Oth=Other

Biological Productivity

Mean values for oxygen flux, due to photosynthesis and respiration, were calculated as 0.70 mg/L.h for Kookoo Lake over a 12 hour period, compared to .97 mg/L.h for Triangle Lake, over an 8 hour

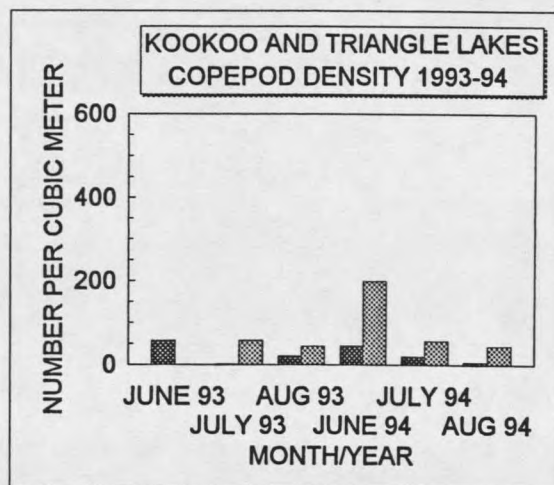
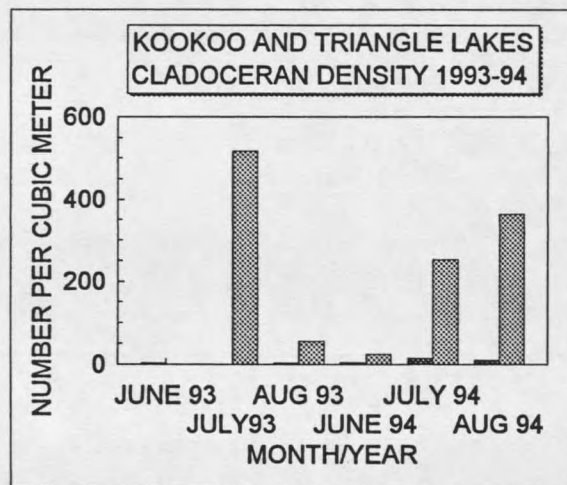
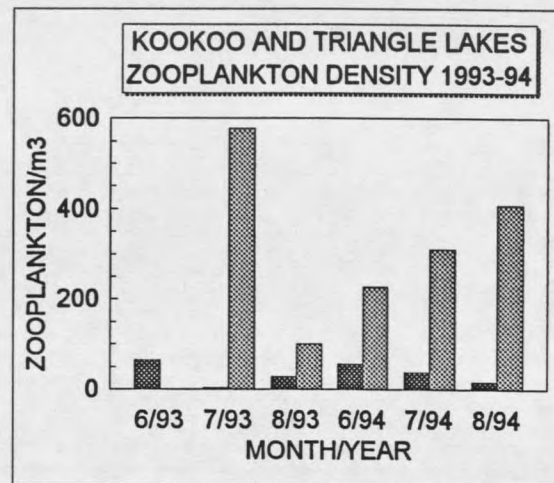
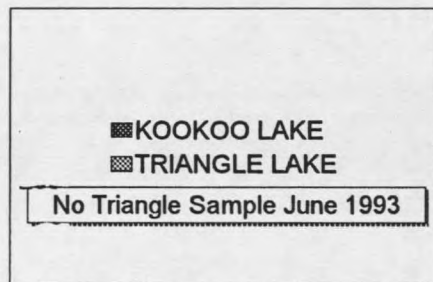


Figure 23. Zooplankton density of Kookoo Lake and Triangle Lake, June, July and August, 1993 and 1994.

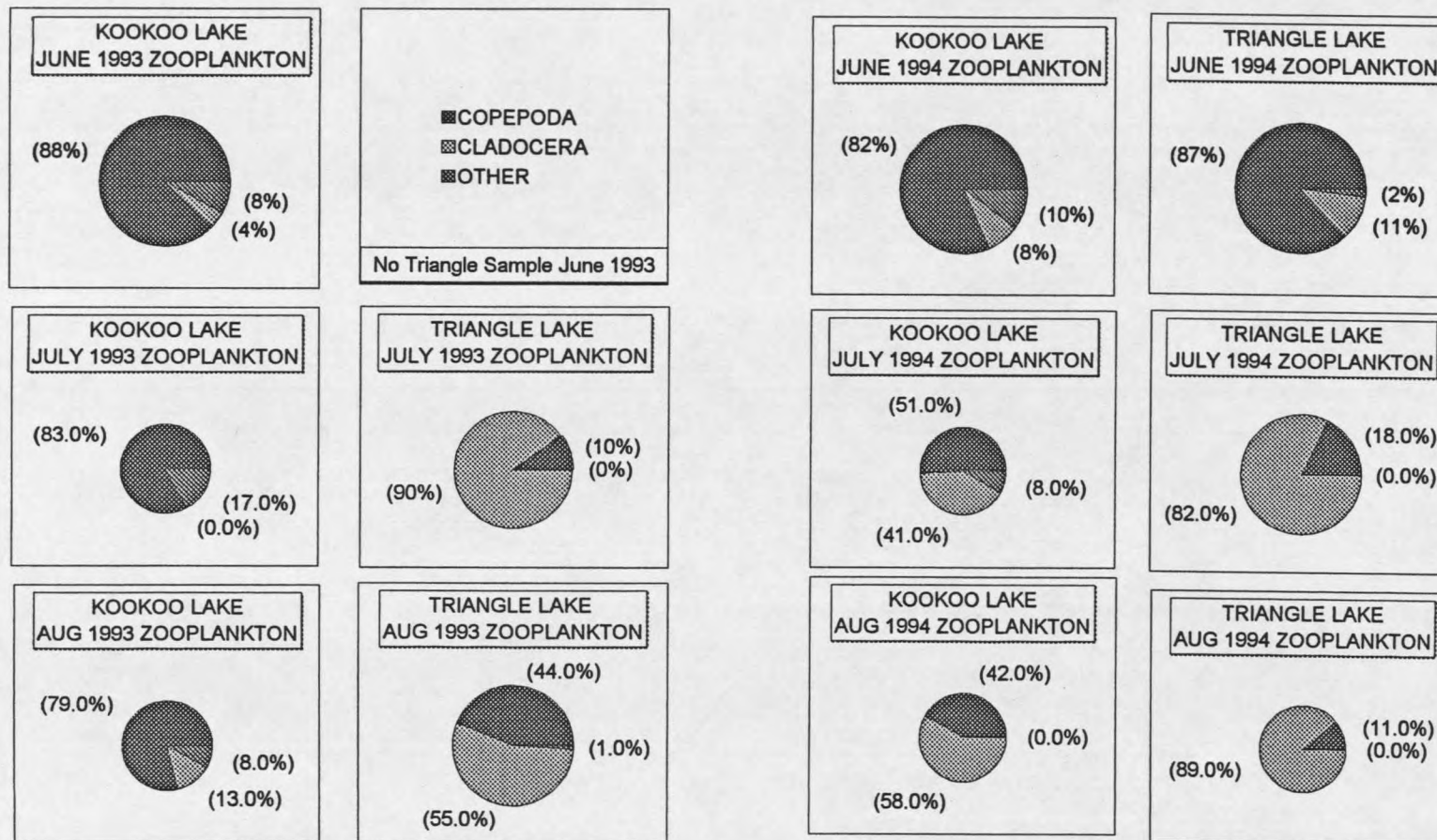


Figure 24. Zooplankton community composition of Kookoo Lake and Triangle Lake in 1993 and 1994.

period(Figure 25). This indicates that Triangle Lake has higher rates of biological activity than Kookoo Lake.

When rates of CO_2 fluctuation were examined through diel pH change, more biological activity was again noted in Triangle Lake. Triangle Lake produced 0.031 mg/L.h of CO_2 , compared to 0.007 mg/L.h in Kookoo Lake(Figure 25).

Since photosynthesis produces oxygen and respiration produces CO_2 , these flux measurements indicate biological activity through photosynthesis and respiration. Although the relationship of respiration and photosynthesis would be expected to be close to 1:1, photosynthesis was more than an order of magnitude larger than respiration. This discrepancy could not be explained, although the differential titration used to convert pH changes into mg of CO_2 increases the possibility of error.

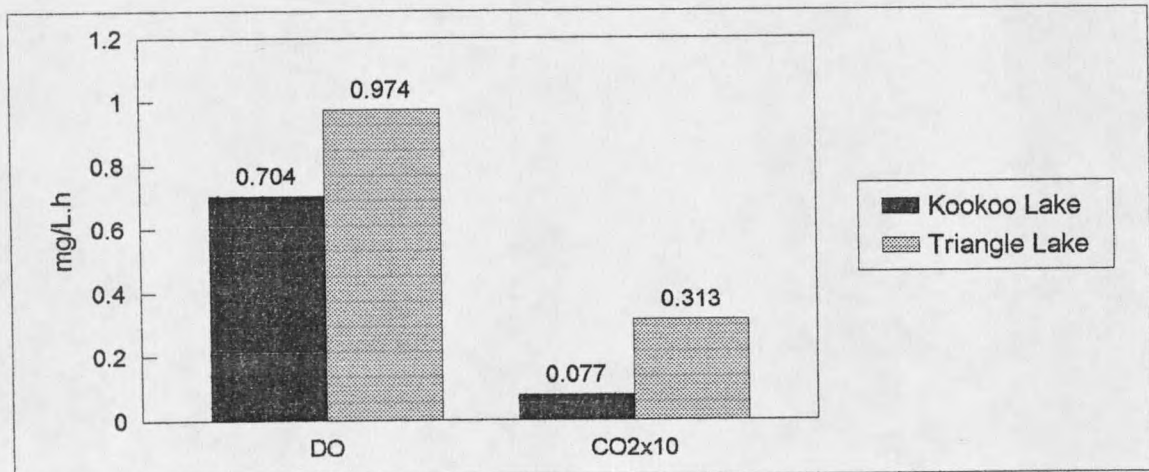


Figure 25. Mean values for DO and CO_2 flux in Kookoo Lake and Triangle Lake measured over 24 h.

During the last week of July, 1994, chlorophyll-a concentration(Figure 21), DO production(Figure 16) and CO_2 production(Figure 25) were higher in Triangle Lake, indicating a greater biological productivity in Triangle Lake than Kookoo Lake, at the time these measurements were taken.

Available nutrients, Nitrogen and Phosphorus

Nitrogen

Kookoo Lake had higher concentrations of available nitrogen in the form of nitrate or nitrite, than Triangle Lake in June, July and August of 1994 (Figure 26, Tables 30, 31 Appendix L). Values were more than double in June (0.069 vs 0.025 mgNO₃/L), and July (0.077 vs 0.034 mgNO₃/L) and 12 times higher in August (0.056 vs 0.004 mgNO₃/L). Nitrogen concentration in Kookoo Lake dropped off in August, as soluble reactive phosphorus (SRP) concentrations increased, indicating an SRP limitation.

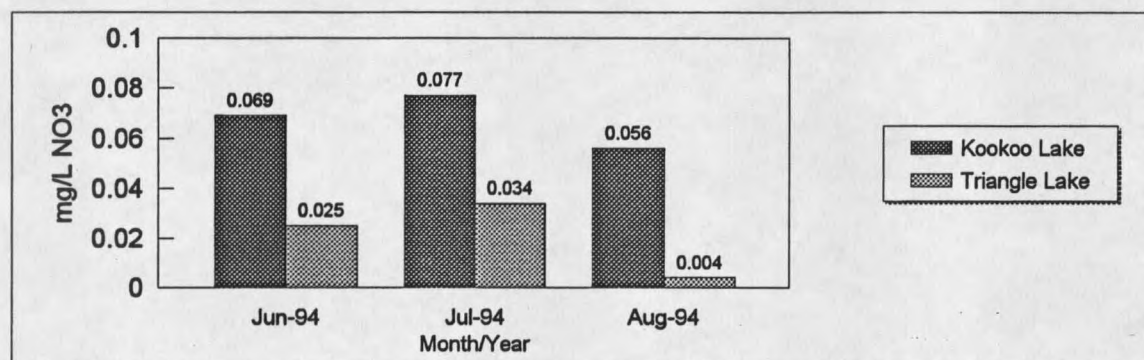


Figure 26. Mean nitrate/nitrite-N concentration calculated as mgNO₃/L. Kookoo Lake and Triangle Lake in June, July and August 1994

Although nitrogen was also found to be available in the form of ammonia, concentrations were a magnitude lower than nitrate. Ammonia concentrations in Triangle Lake were double those of Kookoo Lake in June (0.004 vs 0.002 mgNH₃/L), and August (0.012 vs 0.006 mgNH₃/L), and four times higher in July (0.013 vs 0.003 mgNH₃/L). Depth profiles of nitrogen concentrations show little variation, indicating that the water column is fairly well mixed (Figure 27).

Phosphate

Soluble reactive phosphorus (SRP-PO₄) concentrations were relatively constant in 1994 (0.0045 to 0.0049 mgPO₄/L) in Triangle Lake and were

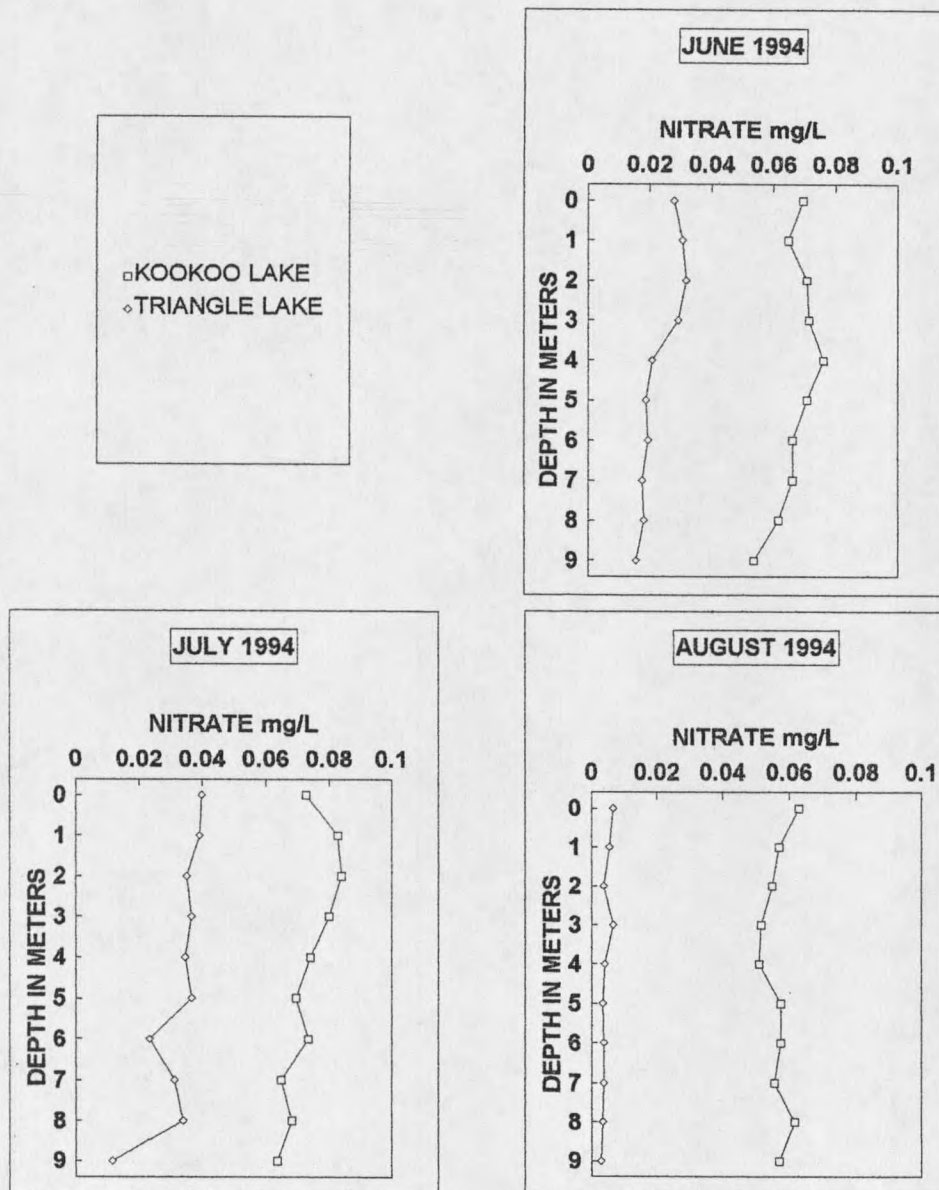


Figure 27. Available nitrogen as nitrate in profile for Kookoo Lake and Triangle Lake, June, July and August 1994.

higher for June (0.0042 vs 0.0023 mgPO₄/L) and July (0.0045 vs 0.0035 mgPO₄/L) than Kookoo Lake, indicating that some other factor (nitrogen) is limiting this system (Figure 28). Soluble reactive phosphorus concentrations increased in August in Kookoo Lake, as nitrogen concentrations declined.

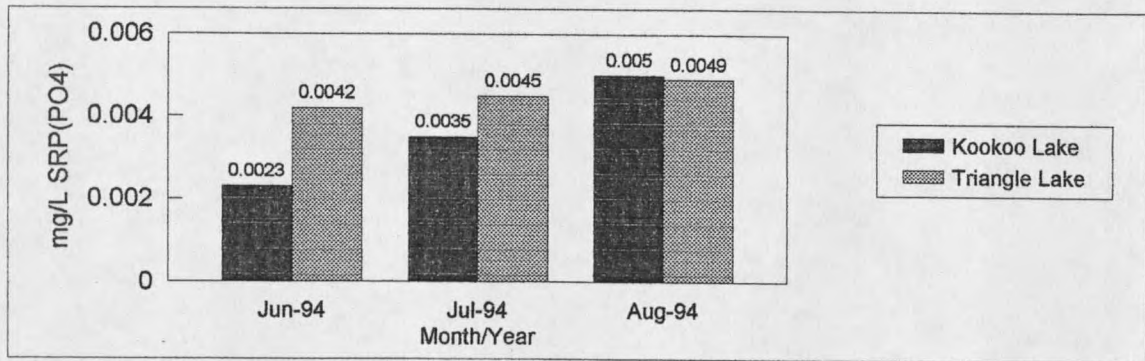


Figure 28. Mean soluble reactive phosphorus-PO₄ concentrations for Kookoo and Triangle Lakes in June, July, and August 1994.

Nitrogen Phosphate Ratios

A Nitrogen to Phosphorus (NP) ratio of 16:1 is considered balanced for aquatic ecosystems (Redfield 1958; Redfield et al. 1963). The NP ratio for Kookoo Lake was 23:1, 20:1 and 9:1 for June, July and August 1994 respectively. This strongly indicates a phosphorus limitation in June and July. Triangle Lake had NP ratios of 3:1, 12:1 and 7:1 for June, July and August 1994 respectively, indicating nitrogen limitation in this lake.

Fish Growth and Health Assessment

Fish Growth

Both Kookoo Lake and Triangle Lake were to be stocked with cutthroat trout at identical densities (244/ha) by helicopter, in the summer of 1994. The fish intended for Triangle Lake either did not survive the stocking procedure or were placed in the wrong lake.

Remnant fish from a previous introduction were found in both lakes in 1995. The age-1 fish in Kookoo Lake were not large enough to be sampled by gill nets in 1995, but were successfully obtained in 1996 and 1997 (Table 9, Table 14, 15 Appendix D).

Table 9. Cutthroat trout sampled in Kookoo and Triangle Lake 1995 to 1997

Date	Lake	# Fish	Age in years	Mean length	Ctl	HAI
7/19/95	Kookoo	14	10	43.1 cm	5.00	50
7/10/96	Kookoo	17	2	22.5 cm	3.82	21
9/04/96	Kookoo	17	2	25.6 cm	3.80	30
9/03/97	Kookoo	10	3	29.2 cm	4.03	64
7/19/95	Triangle	1	10	50.8 cm	5.53	40

The average condition factor (Ctl-condition to length) for fish from 50 lakes surveyed in 1995-96 was 3.79 (Stiff 1996). Except for the 10-year old fish, the condition of fish in Kookoo Lake and Triangle Lake was similar to cutthroat trout from other A-B lakes.

The average Health Assessment Index (HAI) (Adams et al. 1993) for 21 lakes surveyed in 1996 (Stiff 1996) was 38 with a standard deviation of 15.8. The HAI of fish sampled in the study lakes fit within the expected range. The July 1996 sample in Kookoo Lake was quite healthy (HAI 21) while the September 1997 sample from was relatively unhealthy (HAI 64). The presence of a cream colored liver was the dominant abnormality noted in the 1997 sample resulting in high HAI values.

CHAPTER 5

DISCUSSION

Analysis of Historical Data

To evaluate growth of cutthroat trout in alpine lakes it was necessary to access historical data and develop a frame of reference for growth expectations in these lakes. The unique nature of the put-grow-and-take fishery in alpine lakes of the Absaroka-Beartooth Wilderness made this possible. In 71 lakes stocked with Yellowstone Cutthroat trout, there is little or no reproduction, due to the absence of suitable spawning substrate. Knowing stocking dates, I could determine ages from sampling dates noted on gill-net forms and calculate mean lengths for each age class for comparative purposes.

Growth Rates in Kookoo Lake and Triangle Lake

The mean lengths for each age of fish obtained from Kookoo Lake and Triangle were compared to means established for the 71 lakes in our database. It was noted that the initial introduction of cutthroat trout to Kookoo Lake using high stocking densities (704/ha), exhibited below average growth (Figure 6), although initial introductions tend to exhibit above average growth (Figure 8). Limited productivity and overstocking are the probable causes for restricted growth, and will be discussed later.

Yellowstone cutthroat trout subsequently stocked in Kookoo Lake at 349/ha grew at an average rate, although records described growth as less than expected (Montana Fish, Wildlife and Parks records). Establishing mean growth rates for A-B lakes has revealed that Montana Fish, Wildlife and Parks growth expectations for alpine lakes were generally higher than the means obtained from historical data.

Growth rates of cutthroat trout were generally above the mean for Triangle Lake. Anecdotal information about large fish (Montana Fish,

Wildlife and Parks records) from the initial introduction of trout, were not corroborated with sampling. However, growth rates of trout in subsequent stockings were generally above average (Figure 7). Higher growth rates can be attributed to low densities of fish, and will be discussed later.

Factors Affecting Growth Rates

Stocking Density

Of the factors measured, stocking density seemed to have the strongest correlation to growth. Stocking density by area was negatively correlated with growth, using stepwise multiple regression ($p=0.003$) (Table 6), and as well as trend analysis ($p=0.042$). Other studies on high elevation lakes report similar findings (Nelson 1987; Donald and Anderson 1982).

The negative correlation between growth and stocking density was also supported by data from Kookoo Lake and Triangle Lake. It was noted that growth in Kookoo Lake improved substantially after a reduction in stocking density by area (Figure 6). Triangle lake has consistently produced good growth at densities below the median stocking density of 311/ha (Figure 7).

Stocking density by volume was positively correlated with growth, apparently contradicting a negative correlation with stock density by area. To explain this anomaly, sample data from lakes above and below the median for volume (43.9 ha*m) were analyzed separately. When analyzed separately there was no correlation with stock density by volume, while the negative correlation to stock density by area was still present ($p=0.009$).

A possible explanation is that shallow lakes should warm more rapidly, increasing both recycling of nutrients and productivity (Hoffman et al. 1996; Chamberlain and Hubert 1996). These lakes would also have higher stocking densities by volume. Larger lakes warm more slowly, and

stratification of the lakes inhibits the distribution of nutrients produced by decomposition. These large lakes have lower stock densities by volume, generally due to their depths. The result is that high stocking densities by volume (observed in more productive shallow lakes) correlate positively with growth.

Elevation

After stocking density by area, lake elevation showed the strongest correlation with growth of trout. Lake elevation correlated negatively with growth rates of cutthroat trout in A-B Lakes (correlation coefficient -0.04969 $p < 0.007$) (Tables 3 and 4). Trend analysis also showed a negative trend associated with higher elevations ($p = 0.061$) (Table 5, Figure 10). Chamberlain and Hubert (1996), and Nelson (1987) reported similar results when studying growth factors for brook trout and rainbow trout, respectively, in alpine lakes.

Extended ice-cover and colder temperatures of higher elevation lakes can work together to restrict productivity, negatively affecting growth rates of trout. Chamberlain and Hubert (1996) noted that higher elevation lakes supported smaller fish. This may be related to macroinvertebrate species abundance and diversity which is also lower in alpine lakes (Hoffman et al. 1996). The few months of open water on these alpine lakes provides most of the yearly food reserves.

The impact of elevation is highly variable, and may well be due to the duration of ice-cover. Factors such as lake size, and geomorphic orientation also influence the duration of ice cover. Large lakes are more exposed to the sun and wind, which melt and break up ice cover. Lakes with southern exposures will be ice-free sooner than those with northern exposures.

Kookoo and Triangle lakes are at elevations above the median (2955 m) and were still ice-covered the first week of July during 2 years of this 4 year study. Because of the elevation both lakes should exhibit

substandard growth. Since Triangle Lake exhibits above average growth and is located above Kookoo Lake, elevation is not likely the main factor restricting growth in Kookoo Lake. is elevation.

Initial Introductions

When fish are first introduced into fishless alpine lakes there is often a food supply that has not been exposed to significant vertebrate predation. On average, Yellowstone cutthroat trout initially introduced into 71 A-B Lakes grew slightly better than fish from subsequent plants(Figure 8), even when stocked at very high densities ($p=0.026$) (Table 4). High initial growth rates were probably due to the abundant food supply associated with fishless lakes(Gliwicz 1984). The trout alter their food supply by eliminating or reducing the numbers of their preferred prey.

Trout preferentially feed on the large macroinvertebrates(Chess et al. 1993; Gliwicz 1984; Hoffman et al. 1996; Leucke 1990). This results in a zooplankton community made up of smaller species that provide a less energy efficient food source. Initial introductions benefit from a community of large planktivores that are unavailable to subsequent plants.

Contrary to observations of other initial introductions, the first introduction into Kookoo Lake at a stocking density of 704/ha(nearly double the average of 385/ha) did not grow well(Figure 6). Subsequent introductions at lower densities have shown better growth(Figure 6), indicating that Kookoo Lake's zooplankton community may have been more susceptible to higher stock densities than other A-B lakes.

Lake Depth

Lake depth was the final factor that provided a significant correlation with growth. Trend analysis showed that greater depth restricted growth($p=0.047$). Depth, volume and surface area of the lakes are related and trend analysis supported this relationship through a

gradually decreasing statistical support (area $p=0.115$, volume $p=0.189$). These results indicate that depth is the most important of these three characteristics, and its influence is reflected to a lesser extent in the other parameters.

Other studies of alpine lakes also report a negative correlation between growth and depth, as shallow lakes tend to be more productive (Hoffman et al. 1996; Chamberlain and Hubert 1996). Shallower lakes warm more quickly as light penetrates to the bottom heating the substrate. These lakes will warm faster due to smaller volume and solar heating of the substrate. Shallow lakes seldom develop a lasting stratification which allows the entire water column to warm.

Heating of the substrate will also increase decomposition and recycling of nutrients. It has been noted that warmer water temperatures increase nitrogen recycling (Elfving et al. 1975) and productivity (Hoffman et al. 1996). If lack of stratification promotes mixing and greater productivity, then a negative correlation between depth and growth should be present.

Nelson (1988) noted that alpine lakes under 40 feet (12 m) deep seldom develop a lasting summer stratification. Since the major source of nutrients in these lakes is recycling due to decay at the substrate (Angelo 1989, Wissmar 1991), stratification can have a major impact on available nutrients within alpine lakes. Water column mixing places nutrients higher in the euphotic zone, allowing higher rates of photosynthesis, although it forces some phytoplankton into the lower light depths. However, in shallow alpine lakes it is not uncommon for the entire water column to be euphotic.

Lakes deeper than 12 m can trap nutrients in the hypolimnion, and nutrient mixing would be inhibited by stratification. Imported nutrients could also be trapped within the hypolimnion if stream-flow and snow melt were of a higher density than the surface waters. In deeper lakes

the nutrients may be trapped below the effective euphotic zone. The colder temperatures and reduced light in the hypolimnion retard photosynthesis (Hoffman et al. 1996), while the cold also slows the rate of decay.

Both Kookoo Lake and Triangle Lake are less than 12 m deep and should benefit from warming, and a mixing of nutrients during the summer. While Kookoo Lake warmed more quickly than Triangle Lake in June 1994, its mean water temperature was 1 C° lower in July and August (Figure 15), probably due to input of water from Bowback Lake (Figure 2). Good growth was observed in Triangle Lake as predicted by its depth, while Kookoo Lake showed a restriction in growth, indicating that some additional influence is present.

Comparison of Kookoo Lake and Triangle Lake

Physical Characteristics

There was little difference in the physical characteristics of Kookoo Lake and Triangle Lake with the exception of discharge and flushing. It was a conclusion of this study that flushing rate was a major factor affecting productivity in Kookoo Lake. The flushing rate of Kookoo Lake was two to four times faster than Triangle Lake (Figure 12). Flushing rates for Kookoo Lake varied from 2.2 d in June of 1994 (during runoff) to 8.6 d in August of 1993 (no August 1994 measurement taken due to low discharge). When flushing rates approach the doubling rates of phytoplankton, a washout of nutrients and phytoplankton may occur (Goldman et al. 1979).

The effect of flushing in Kookoo Lake can be seen in chlorophyll-a (Figure 21) and SRP concentrations (Figure 28), which were lower than Triangle Lake in all months except for August of 1994, when exceptionally low discharge occurred. Since the lowest flushing rate coincided with the highest standing crop of algae and the highest

concentrations of SRP in Kookoo Lake, I concluded that nutrients, algae, or both were subject to a washout during higher discharge.

Other characteristics measured were water clarity and temperature. Water clarity varied widely in both lakes with no obvious trend present in either lake. Water temperature was similar in the two study lakes. Kookoo Lake warmed more quickly than Triangle Lake, as it was 73 m lower in elevation, but was slightly cooler later in the summer, due to high turnover rates.

Chemical Parameters

Dissolved Oxygen and pH.

The water chemistry of the two study lakes was similar with the exception of nitrogen and phosphate profiles (discussed later), and calculated daily flux of dissolved oxygen (DO) and CO_2 . Monthly DO and pH profiles indicated that there was no lasting chemical stratification in either lake during the summer months (Tables 17, 18, and 19), and this was also noted by Nelson (1988).

Daily flux of DO and CO_2 was used to calculate rates of photosynthesis and respiration, respectively. Rates of photosynthesis and respiration give an idea of the relative productivity of the two study lakes. Dissolved oxygen flux for Triangle Lake was 0.97 mg/L.h compared to 0.7 mg/L.h in Kookoo Lake, indicating that rates of photosynthesis, as measured by production of dissolved oxygen, were higher in Triangle Lake.

Using diel shifts in pH to calculate production of CO_2 , higher rates were also noted in Triangle Lake. Triangle Lake CO_2 flux was calculated as 0.031 mg/L.h, compared to 0.007 mg/L.h in Kookoo Lake (Figure 25). This indicates higher respiration rates in Triangle Lake, as well as the photosynthetic rates noted above.

Since photosynthesis measures net productivity, and photosynthesis and respiration are opposing reactions, a summation of the two reactions

gives a better idea of total productivity. Since both respiration and photosynthesis were higher in Triangle Lake, it was concluded that total productivity was higher in Triangle Lake than in Kookoo Lake.

Heavy Metals

Heavy metal concentrations were noted for each lake in 1993, to assess the possibility that naturally occurring heavy metal contamination may be affecting productivity in Kookoo Lake. There was no evidence of heavy metal contamination in either lake (Table 7), and this was not measured in 1994.

Alkalinity

Alkalinity affects the buffering capacity of lakes and was measured as common water quality parameter. Low alkalinity was noted in Kookoo Lake and Triangle Lakes as is typical of alpine lakes (Nelson 1988). Alkalinity was similar in the two study lakes (Figure 20), and doesn't seem to be a factor in the productivity of these lakes.

Biological Characteristics

Chlorophyll-a

Chlorophyll-a concentrations were higher in Triangle Lake during June and July of 1994 (Figure 21). The highest chlorophyll concentrations were generally found near the bottom, and the lowest near the surface (Figure 22). Higher photosynthetic activity near the bottom was probably due to the presence of available nitrogen and SRP supplied through organic decay, and the absence of photoinhibition.

Mean chlorophyll-a concentrations remained about the same in Triangle Lake throughout the study (Figure 24), supplying a constant food source for the zooplankton. In Kookoo Lake chlorophyll-a concentrations were lower than Triangle Lake except in August 1994.

The increase in chlorophyll-a concentrations in August 1994 corresponded with a rise in SRP concentrations (Figure 28), and extremely low lake discharge (Figure 11). It was concluded that the high flushing

rates found in Kookoo Lake resulted in a washout of phosphorus and phytoplankton. When discharge was lowered the phytoplankton population, as measured by chlorophyll-a concentrations, rebounded.

Benthos

Benthos populations were similar in Triangle Lake and Kookoo Lake and were composed almost exclusively of chironomids (Appendix c Table 13). Gut content analysis from other A-B lakes indicates that the principal food items at ice-out in early July are chironomids (Stiff 1996). Other researchers on high mountain lakes report similar findings (Chess 1993, Luecke 1990, Nost and Jensen 1997). Chironomids are an inefficient food source for trout, which prefer cladocerans (Gliwicz 1984). After spring turnover, gut contents of trout in other A-B lakes include larger numbers of cladocerans (Stiff 1996).

Since both Kookoo Lake and Triangle Lake have similar benthos populations consisting of chironomids, it is unlikely that the difference in growth exhibited by the two lakes is related to benthos.

Zooplankton

Zooplankton densities in Kookoo Lake were much less than nearby Triangle Lake (Figure 26), and the community structure showed a marked reduction in the percent of cladocerans (Figure 27). Several studies have verified the impact of trout on zooplankton populations in alpine and other lakes (Gliwicz 1984; Nost and Jensen 1997; Schriver et al. 1995), indicating that the lower densities found in Kookoo Lake could be related to trout populations. Salmonid planktivores selectively choose some types of zooplankton as a food source (Gliwicz 1984; Lucas 1993; Nost and Jensen 1997).

Cladocerans are eaten by trout preferentially over copepods (Gliwicz 1980; Schriver et al. 1995; Lucas 1993; Nost and Jensen 1997) and August 1994 was the only month that cladocerans dominated the zooplankton community in Kookoo Lake. Cladocerans dominated the

zooplankton community in Triangle Lake throughout the study with the exception of June 1994.

It is not known if the increase in the cladoceran population in Kookoo Lake was a result of decreased trout abundance over the summer, or increased densities of phytoplankton as a food source, or a combination of these factors.

If the increase in cladocerans in Kookoo Lake was a response to increases in photosynthesis, there should have been an increase in total zooplankton density, and this was not apparent (Figure 23). However, the impact of trout on the zooplankton community has been well documented (Luecke 1990; Chess et al. 1993; Hoffman et al. 1996). Since the overall zooplankton density did not increase with this shift in community structure, the increase in cladocerans was probably due to the declining trout population.

Zooplankton density and productivity were both lower in Kookoo Lake than Triangle Lake making Kookoo Lake more susceptible to the impact of predators. The high initial stocking density of cutthroat trout in Kookoo Lake impacted the zooplankton population, resulting in a population dominated by the less-preferred copepods. Cladocerans became dominant during August of 1994, when the majority of trout had been removed or had died out.

Nutrients

Nitrogen or phosphorus availability are often the limiting factors in lakes of the western United States. Angelo (1989) demonstrated a nitrogen limitation in another Absaroka-Beartooth Wilderness Lake, while Dodds and Prisco (1990) reported a colimitation of P and N in Flathead Lake, MT. Other studies have documented P limitation in high mountain lakes (Reche et al. 1994).

When I examined nutrient concentrations in Kookoo Lake and Triangle Lake, nitrate/nitrite-N concentrations were higher in Kookoo

Lake, except for August 1994 (Figure 26). Conversely, soluble reactive phosphorus (SRP) concentrations were lower in Kookoo Lake than Triangle Lake (Figure 28). Since higher SRP concentrations in August 1994 correspond with an increase in chlorophyll-a concentrations (Figure 21) and a drop in nitrogen concentrations, it is likely that phosphorus is the limiting nutrient in Kookoo Lake. Higher SRP concentrations triggered an increase in phytoplankton, which in turn removed nitrogen from the system.

A nitrogen:phosphorus (N:P) atom ratio of 15-16:1 is traditionally associated with balanced nutrient availability in aquatic environments (Redfield 1958; Redfield et al. 1963) and can be used as a test for nutrient limitations. The N:P ratios in Kookoo Lake indicated a phosphorus limitation at levels of 23:1 and 20:1 in June and July, while a 9:1 ratio was noted for August indicating a nitrogen limitation, corresponding to higher chlorophyll-a concentrations. A nitrogen limitation was noted for June, July and August 1994 in Triangle Lake, with N:P ratios of 3:1, 12:1 and 7:1, respectively.

The correspondence of an increase in SRP concentration and lowering of the N:P ratio to an increase in chlorophyll-a concentration, indicates that productivity in Kookoo Lake is mainly limited by phosphorus concentrations. Lower SRP concentrations correspond to higher flushing rates indicating that flushing rate affects nutrients (phosphorus) and phytoplankton by washing them downstream.

Low phosphorus concentrations may also be affecting the zooplankton community more directly as well. Hessen and Anderson (1992) demonstrated a greater phosphorus to dry weight ratio in cladocerans than copepods, indicating a greater need for phosphorus. Examining zooplankton populations in Kookoo Lake reveals that copepods were the dominant family in the zooplankton community of Kookoo Lake in June and

July, when SRP concentrations were low, while cladocerans dominated the community in August, when SRP concentrations were much higher.

Summary of Kookoo Lake and Triangle Lake

Both Kookoo Lake and Triangle Lake were originally fishless lakes. Both are at about 3100 m elevation, and are about 2.5 ha with a maximum depth of about 9 m (Table 1, Table 10). Kookoo Lake had always been stocked at densities (by area) higher than the median of 311 per ha, and has produced average or poor growth of cutthroat trout (Figure 6). Triangle Lake has always been stocked at densities below the median and has produced larger trout (Figure 7).

Table 10. A summary of physical, chemical and biological differences noted during this study comparing Kookoo Lake and Triangle Lake.

Parameter	Kookoo Lake	Triangle Lake	Similar or variable
Elevation			similar
Maximum depth			similar
Discharge/Flushing	Higher	lower	
Mean depth	Shallower	deeper	
Area			similar
Volume	Lower	higher	
Temperature			variable
Presence of outlet lake	Absent	present	
Water clarity			variable
SRP concentration	Lower	higher	
Available nitrogen	Higher	lower	
N:P atom ratios	Higher	lower	
pH	Higher	lower	
DO			similar
Alkalinity			similar
Fish growth	Slower	faster	
Dominant zooplankton	Copepoda	Cladocera	
Zooplankton density	Lower	higher	
Chlorophyll concentration	Lower	higher	
Productivity	Lower	higher	
Stocking density by area	Higher	lower	

This study looked at characteristics that may have resulted in the unexpectedly low growth of trout observed in Kookoo Lake, in addition to stocking density. Kookoo Lake had a shallower mean depth, and less volume (Table 1, Table 10). Higher discharge rates combined with lower

volume to accelerate flushing rates. The high flushing rates result in a washout of nutrients and phytoplankton in most months of the summer, restricting productivity. Lowered productivity translated into lower phytoplankton concentrations, and subsequently lower zooplankton densities. The lower zooplankton densities made the zooplankton community more susceptible to predation.

The cutthroat trout originally planted at high densities in Kookoo Lake impacted the zooplankton community causing a shift towards a community dominated by copepods (Figure 24). Subsequent stockings at lower densities did produce average growth rates, although trout still exhibit better growth in Triangle Lake.

Cutthroat trout in Triangle Lake have shown excellent growth because it has always been stocked at lower densities, and some trout migrate downstream to an outlet lake further lowering the trout density.

Management Implications

Management plans for stocking trout in alpine lakes have traditionally used stocking density or population density by area as the major factor in predicting growth of trout (Poore and Marcuson 1991). Elevation has been a consideration used in planning some alpine lake introductions (Nelson 1987). This study found that both of these factors correlate negatively with growth of cutthroat trout, supporting earlier findings, and indicating that higher elevation lakes should have lower stocking densities.

This study also noted that initial introductions of fish will grow better than subsequent introductions. When higher than expected growth rates take place from initial introductions, it does not necessarily indicate the capacity for higher densities of trout for subsequent stockings. Similarly, slower growth of trout in subsequent introductions may just indicate a shift in zooplankton community. If a

return to the original zooplankton community is desirable, fish should be stocked intervals of at least 10 years, since Yellowstone cutthroat trout commonly live 9 or 10 years in A-B lakes.

Depth of lakes should be a consideration when planning alpine lake introductions. Shallow lakes show greater productivity (Hoffman et al. 1996; Chamberlain and Hubert 1996), and larger, deeper lakes are less productive. In alpine lakes, lasting summer stratification occurs at 12 m (Nelson 1988). This may provide a reference for distinguishing shallow lakes from deep lakes. Stocking densities by area should be adjusted to reduce numbers of trout stocked in deeper lakes.

My study demonstrated that discharge from lakes can become a factor in productivity when it results in a washout of nutrients and phytoplankton. The high turnover rates noted for alpine lakes (Arneson 1969; Wells 1986; Angelo 1989), makes a washout of nutrients a significant consideration for small alpine lakes. It should also be noted that shallow lakes with high discharge are more subject to a washout than deeper lakes even though they are more productive.

Factors examined for their impact on growth rates of trout during this study were elevation, depth, area, volume, stocking sequence, stocking density by area, and stocking density by volume. Stocking density by area, elevation, depth, and stocking sequence all correlated negatively with growth rates (Table 6). A multiple regression of these factors for 248 samples produced an r^2 of 9.9% (Table 3), resulting in the conclusion that over 90% of growth is influenced by factors that have not been examined.

Further Study

There are numerous problems associated with conducting a study far within the boundaries of a wilderness, and any study contemplated needs to account for the unique nature of an alpine wilderness (Appendix M).

I used only two lakes for this extensive look at two alpine systems, and the interpretation of the data is limited by small sample size. In the historical study, using data from 71 lakes allowed for a great deal of overlap and variation, but data did not include a number of important factors, such as flushing rates and multiple stockings, making it difficult to determine cause and effect. It is suggested that a better approach would be to study five lakes with the poorest growth and five lakes with the best growth rates.

For this sort of study a number of additional factors could be compared:

time of ice-out

discharge and flushing rate

lake order within the drainage

size of basin draining into the lake

average irradiance available in the lake and lake turbidity

Elevation showed a slight effect on growth at higher elevations. It would be wise to correlate date at ice-out with growth to see if it is a cause of the negative influence of elevation.

This study suggests a mechanism by which SRP can become a limiting factor in alpine lakes. A high discharge and associated high flushing rate may affect SRP concentration flushing nutrients from the lake. Lake order within a drainage may also have an impact on nutrients, with lake order defined as the numbering of lakes present along a drainage, starting at the headwaters. Triangle Lake is a third order lake, while Kookoo is the lowest of six lakes (sixth order) within this basin. As such it has a larger drainage area.

Some alpine lakes are situated in mountainous basins restricting the amount of direct sunlight available. A reduction in available light can restrict the amount of photosynthesis, and also retard warming of the water during the summer.

CHAPTER 6

CONCLUSIONS

During this study of factors that could have resulted in the poor growth rates of cutthroat trout in Kookoo Lake in the Absaroka-Beartooth Wilderness, the following items were identified as possible causes:

1. High flushing rates within Kookoo Lake are restricting phytoplankton and zooplankton growth by flushing nutrients and organisms from the system before they can reproduce. Flushing was much higher in Kookoo Lake, during all months, except in August of 1994 when SRP and chlorophyll concentrations were higher than previous months.
2. Nitrogen:phosphorus atom ratios and SRP concentrations in Kookoo Lake indicate that a phosphate limitation generally occurs in Kookoo Lake.
3. Chlorophyll-a concentrations were always lower in Kookoo Lake except for August 1994, which corresponds with lower flushing rate and higher SRP concentrations.
4. Diel measurements of DO and pH revealed lower productivity in Kookoo Lake.
5. The zooplankton density was much lower in Kookoo Lake due to lower productivity and the high stocking densities used in the initial introduction of cutthroat trout.
6. The zooplankton community in Kookoo Lake is dominated by copepods, an order of crustacean that is not preferred by cutthroat trout.
7. The first plant of cutthroat trout in Kookoo Lake exhibited poor growth due to the lower productivity of the lake, and the high density of trout stocked(704/ha). The lower productivity in Kookoo Lake made the zooplankton community more susceptible to the impact of predation.
8. The second plant of cutthroat trout in Kookoo Lake at lower

densities(349/ha) grew at average rates contradicting the idea that trout had consistently grown poorly in the lake.

9. Triangle Lake had better growth rates of cutthroat trout due, to its greater productivity, and due to the lower stocking densities used. Stocking densities were probably further lowered by downstream migration of trout.

Analysis of historical data suggested that the following characteristics of alpine lakes have an impact on growth rates.

10. Stocking density by area correlates negatively with growth rates ($p=0.003$).
11. Trout introduced into lakes with higher elevations show reduced growth rates ($p=0.007$) due to food limitations.
12. Growth of trout associated with initial introductions is generally better than subsequent stockings, even when done at above average stocking densities ($p=0.026$), since trout alter the zooplankton community within the lake, causing a shift to less preferred species.
12. Deeper alpine lakes (>12 m) restrict growth rates ($p=0.047$). These generally have greater area and volume as well, and these two factors also restrict growth rates to a lesser extent. Using mean depth may provide a more useful tool, as it includes these parameters. Summer stratification of deeper lakes may inhibit recycling of nutrients and trap nutrients in the hypolimnion.

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APPENDICES

APPENDIX A

Stocked cutthroat trout lakes in the Absaroka-Beartooth Wilderness.

Table 11. Physical characteristics of stocked cutthroat trout lakes in the Absaroka-Beartooth Wilderness.

Lake	Elevation m	Area ha	Depth m	Lake	Elevation m	Area ha	Depth m
Albino Lake	3048	15.9	45.4	Mermaid Lake	2957	2.8	9.1
Alpine Lake	2646	4.3	6.1	Moon Lake	3170	3.3	35.0
Anvil Lake	3287	4.1	13.7	Mountain Goat Lake	3060	5.1	18.3
Arch Lake	3085	2.6	16.5	Mountain Sheep Lake	3043	3.0	5.5
Avalanche Lake	2972	25.1	41.1	Mouse Lake	2941	2.8	9.1
Black Canyon Lake	2829	33.4	56.3	Narrow Escape Lake	2847	4.7	6.1
Blacktail	2652	1.7	6.1	Nemidji Lake	2925	5.5	7.2
Blue Lake	2883	4.2	8.3	N. Picket Pin Lake	2690	2.1	6.1
Bowback Lake	3164	2.6	12.2	Nugget Lake	2847	3.4	9.1
Bramble Lake #39	2675	1.3	7.9	Shadow Lake	2920	1.5	1.8
Bramble Lake #41	2903	1.7	21.3	Silt Lake #3	2993	1.3	2.1
Bridge lake	2922	5.7	12.8	S. Picket Pin Lake	2751	2.0	5.8
Courthouse Lake	3048	7.6	62.5	Speculator Lake	2880	3.9	11.6
Crystal Lake	3021	11.1	25.9	Star Lake	2940	3.2	11.0
Davis Lake	2680	2.1	4.6	Stash Lake	3043	1.3	7.3
Dude Lake	3103	4.9	6.1	Stephanie Lake	3127	5.6	19.8
Eedica Lake	2963	3.6	12.2	Sundance Lake	2856	1.2	5.2
Elk Lake	2920	2.5	6.7	Sundown Lake	2896	2.1	X
Flat Rock Lake	3045	15.0	25.4	Surprise Lake	3005	2.9	10.1
Fossil Lake	3018	66.7	45.7	Swamp Lake	2713	4.2	6.4
Golden Lake	3088	19.8	27.4	Swede Lake	2991	4.8	25.6
Hipshot Lake	2941	3.9	14.3	Trail Lake	2987	2.9	16.7
Horseshoe Lake	2798	2.0	4.0	Triangle Lake 10	2966	3.2	10.7
Jasper Lake	3093	22.2	32.6	Triangle Lake 60	3182	2.6	10.7
Kookoo Lake	3109	2.5	9.1	Triangle Lake 110	2996	2.6	16.8
Lake Abundance	2540	7.0	11.3	Upper Aero Lake	3091	117.8	59.4
Lake of the Clouds	2951	9.6	25.9	Upper Arch Creek Lake	3085	19.0	34.1
Lake of the Winds	3021	16.5	56.7	Weasel Lake #51	3014	2.2	10.7
Leaky Raft Lake	3093	3.4	9.1	Weasel Lake	3030	1.5	6.1

Table 11. (continued)

Lake	Elevation m	Area ha	Depth m	Lake	Elevation m	Area ha	Depth m
Line Lake	2951	1.9	7.9	Weeluna Lake	2955	4.1	9.1
Lower Storm Lake	2999	7.2	30.0	Weidy Lake	2746	2.8	20.7
Margaret Lake	2469	1.6	6.7	W. Boulder Lake	2935	5.3	16.8
Marker Lake	3313	6.3	35.1	Wood Lake	2954	4.9	11.6
Marsh Lake	2749	1.5	7.6	Wrong Lake	2744	8.3	35.4
Martes Lake	2789	7.1	10.0	Zimmer Lake	3091	10.5	16.8
Medicine Lake	3019	12.3	12.8				

APPENDIX B

Alkalinity, conductivity and hardness.

Table 12. Alkalinity, conductivity, and water hardness of Kookoo and Triangle Lake, June, July and August 1993 and 1994..
Alkalinity and hardness are measured in mg CaCO₃/L.

Parameter	Lake	6/93	7/93	8/93	6/94	7/94	8/94
Alkalinity	Kookoo	138.0	6.0	23.0	12.0	7.5	16.5
mg/L	Triangle	102.0	33.0	57.0	10.0	5.3	11.0
Conductivity	Kookoo	130	151	28			
micromhos	Triangle	22	72	25			
Hardness	Kookoo	103	35	18			
mg/L	Triangle	122	110	45			

APPENDIX C

Benthos sampled in 1993, 1994.

Table 13. Name and number of benthic organisms counted from substrate samples taken in June, July and August 1994.

Date	Organism	Kookoo Lake Sample size	Kookoo Lake Number	Kookoo Lake # per liter	Triangle Lake Sample size	Triangle Lake Number	Triangle Lake # per liter
June '93	<i>Chironomas</i>	360 mL	Spoiled		360 mL	spoiled	
July '94	<i>Chironomas</i>	100 mL	5	50	60 mL	7	7
	Plecoptera					2	2
August '94	<i>Chironomas</i>	360 mL	42	117	360 mL	2	5.6

APPENDIX D

Gill-net data from Kookoo and Triangle Lake.

Table 14. Stocking and gill net data for Kookoo Lake 1976-1997.

Year	Age	Mean (cm)	Ctl	HAI	Density/ha	Stocking
1976	4	24.1	3.23		704	First
1977	5	26.4	3.01		704	First
1978	6	27.9	3.18		704	First
1979	7	25.9	3.38		704	First
1980	8	29.2	3.17		704	First
1981	9	31.0	3.86		704	First
1990	5	31.0			349	Second
1993	8	36.8	3.75		349	Second
1994	9	39.6	3.97		349	Second
1995	10	43.2	4.70	50	349	Second
1996 July	2	22.4	3.88	21	244	Third
1996 Sept	2	25.4	4.05	30	244	Third
1997	3	29.2	3.62	64	244	Third

Table 15. Stocking and gill net data for Triangle Lake 1978-1995.

Year	Age	Mean (cm)	Ctl	HAI	Density/ha	Stocking
1978	1	14.2	3.81		242	Second
1979	2	23.9	4.20		242	Second
1980	3	32.3	3.65		242	Second
1981	4	34.5	3.79		242	Second
1986	1	25.7	3.83		252	Third
1990	5	40.9	3.83		252	Third
1994	9	49.0	5.70		252	Third
1995	10	50.8	4.75	40	252	Third

APPENDIX E

Trend analysis of four factors that affect growth of cutthroat trout.

Table 16. Percent of lakes exhibiting below average growth associated with elevation, depth, area and volume, with lakes divided into those above and below the median for each parameter.

Age	n	Above/ below median	Median elevation 2955 m		Median depth 11.4 m		Median area 8.8 ha		Median volume 43.9 ha*m	
			% Below average Growth	n	% Below average Growth	n	% Below average Growth	n	% Below average Growth	n
1	17	Above	62%	8	62%	8	67%	9	78%	9
		Below	56%	9	44%	9	50%	8	37%	8
2	36	Above	64%	16	60%	15	60%	15	56%	14
		Below	35%	20	38%	21	38%	21	35%	22
3	35	Above	71%	14	75%	12	77%	13	77%	13
		Below	62%	21	61%	23	59%	22	59%	22
4	33	Above	72%	18	74%	19	77%	18	50%	17
		Below	47%	15	43%	14	53%	15	71%	16
5	28	Above	59%	17	56%	9	56%	16	57%	14
		Below	45%	11	53%	19	50%	12	50%	14
6	27	Above	56%	16	65%	17	56%	9	57%	7
		Below	54%	11	40%	10	56%	18	55%	20
7	36	Above	47%	17	52%	21	43%	21	50%	22
		Below	58%	19	53%	15	67%	15	57%	14
8	14	Above	60%	5	29%	7	25%	8	29%	7
		Below	44%	9	71%	7	83%	6	71%	7
9	16	Above	56%	9	62%	8	50%	8	56%	9
		Below	43%	7	37%	8	50%	8	43%	7
10	6	Above	0%	0	100%	3	0%	1	0%	1
		Below	50%	6	0%	3	40%	6	40%	5
Ave		Above	61%	120	62%	119	58%	118	56%	113
		Below	50%	128	48%	129	54%	130	52%	135
p=		Above	0.060		0.047		0.115		0.189	
cl		Above	88%		91%		78%		65%	

cl=confidence level

APPENDIX F

Secchi measurements and calculations.

Table 17. Secchi depths, extinction coefficients, and total light extinction for Kookoo Lake, June, July and August 1993 and 1994.

Date	7/01/93	7/27/93	8/18/93	6/30/94	7/27/94	8/16/94
Depth	7.00 m	raft	4.80 m	5.75 m	6.25 m	5.50 m
Ext. coef	0.243	x	0.354	0.296	0.272	0.309
Extinction	14.0 m	x	9.6 m	11.5 m	12.5 m	11.0 m

Ext. coef = Extinction Coefficient
values are averages of three trials

Table 18. Secchi depths, extinction coefficients, and total light extinction for Triangle Lake, June, July and August 1993 and 1994.

Date	6/30/93	7/28/93	8/17/93	6/29/94	7/26/94	8/17/94
Depth	Frozen	9.00 m	4.50 m	4.45 m	7.00 m	9.75 m
Ext. Coef	X	0.189	0.378	0.382	0.243	0.174
Extinction	X	18.0 m	9.0 m	8.9 m	14.0 m	19.5 m

Ext. Coef = Extinction Coefficient
values are averages of three trials

APPENDIX G

Dissolved oxygen profiles.

Table 19. Dissolved oxygen profiles in mg/L for Kookoo Lake, June, July and August 1993 and 1994.

Date- Depth m	6/93	7/93	8/93	6/94	7/94	8/94
0	9.13	9.08	9.15	7.77	7.38	7.60
1	8.93	8.68	8.95	7.57	6.93	7.55
2	9.03	8.58	8.75	7.42	8.96	7.80
3	9.13	8.48	8.45	7.32	7.13	7.82
4	9.33	8.18	8.35	7.27	7.15	7.90
5	8.93	8.18	8.35	7.32	7.48	8.02
6	6.53	8.08	8.35	7.32	7.63	7.98
7	3.53	7.98	8.35	7.57	7.63	7.91
8	0.43	7.98	8.25	7.72	7.33	7.80
9		7.98		6.77	7.43	7.00
B					6.93	

Table 20. Dissolved oxygen profiles in mg/L for Triangle Lake, June, July and August 1993 and 1994. Lake was frozen in June 1993.

Date- Depth m	6/93	7/93	8/93	6/94	7/94	8/94
0	9.57	8.90	8.97	8.38	6.99	7.08
1		8.30	8.77	7.98	6.72	7.16
2		8.20	8.57	7.83	6.57	7.29
3		8.20	8.47	8.38	6.47	7.27
4		8.20	8.47	7.98	6.42	7.28
5			8.47	7.83	6.42	7.28
6			8.37	8.28	6.47	7.38
7			8.37	8.40	6.47	7.18
8			8.37	8.58	6.87	7.23
9				8.58	5.27	7.33
B				8.48	2.77	8.48

APPENDIX H

Diel dissolved oxygen fluctuation.

Table 21. Dissolved oxygen profiles in mg/L for Kookoo Lake. Taken every 4 h on July 27-28, 1994. Values were taken to calculate oxygen flux over 24 h.

Time- Depth m	1145	1545	1945	2345	0345	0745
0	7.33	7.45	7.36	Windy	7.70	7.75
1	6.88	7.10	7.11		7.35	7.50
2	8.91	6.87	7.11		7.75	7.40
3	7.08	7.30	7.16		7.75	7.80
4	7.10	7.47	7.24		7.95	8.00
5	7.43	7.60	7.21		8.05	8.15
6	7.58	7.50	7.31		8.10	8.20
7	7.58	7.70	7.66		8.10	8.20
8	7.28	7.70	7.81		7.70	8.15
9	7.38	6.55	8.11		7.70	7.95
B						

Table 22. Dissolved oxygen profiles in mg/L for Triangle Lake. Taken every 4 h on July 26-27, 1994. Values were taken to calculate oxygen flux over 24 h.

Time- Depth m	1415	1815	2215	0230	0615	1015
0	7.05	7.22	7.20	7.20	7.36	7.30
1	6.78	7.02	7.50	7.15	7.11	7.20
2	6.63	7.22	7.55	6.50	7.11	7.25
3	6.53	7.25	7.55	6.75	7.16	7.20
4	6.48	7.25	7.75	6.70	7.24	7.50
5	6.48	7.29	7.60	6.76	7.21	7.45
6	6.53	7.34	7.80	6.85	7.31	7.30
7	6.53	7.49	8.05	7.30	7.66	7.60
8	6.93	7.85	8.55	7.50	7.81	7.75
9	5.33	7.79	8.60	7.75	8.11	7.75
B						

APPENDIX I

pH profiles.

Table 23. Kookoo Lake pH profiles for June, July and August 1993 and 1994. Measurements were taken at the surface in 1993.

Date- Depth m	6/93	7/93	8/93	6/94	7/94	8/94
0	6.70	7.00	7.10	7.28	7.52	8.68
1				7.12	7.34	8.79
2				7.22	7.26	8.88
3				7.24	7.25	8.93
4				7.24	7.33	8.92
5				7.23	7.42	8.81
6				7.06	7.51	8.66
7				7.17	7.49	8.62
8				7.37	7.39	8.55
9				7.53	7.42	8.49
B						

Table 24. Triangle Lake pH profiles for June, July and August 1993 and 1994. Measurements were taken at the surface in 1993.

Date- Depth m	6/93	7/93	8/93	6/94	7/94	8/94
0	6.60	7.00	7.20	6.86	7.11	8.13
1				6.79	7.23	8.26
2				6.77	7.23	8.21
3				6.78	7.45	8.23
4				6.88	7.25	8.27
5				7.00	7.17	8.07
6				7.10	7.28	8.19
7				7.18	7.42	8.23
8				7.02	7.33	8.16
9				6.74	6.94	8.16
B						

APPENDIX J

Diel pH fluctuation.

Table 25: Kookoo Lake pH taken every 4 h on July 27-28, 1994.
Values were used to calculate CO₂ flux due to respiration over 24 h.

Date- Depth m	1145	1545	1945	2345	0345	0745
0	7.52	7.74	7.53	Windy	7.46	7.28
1	7.34	7.49	7.48		7.44	7.27
2	7.26	7.34	7.45		7.39	7.20
3	7.25	7.29	7.44		7.38	7.22
4	7.33	7.27	7.51		7.47	7.24
5	7.42	7.67	7.52		7.58	7.45
6	7.51	7.60	7.53		7.68	7.58
7	7.49	7.75	7.83		7.68	7.58
8	7.39	7.77	8.22		7.63	7.51
9	7.42	7.72	8.49		7.63	7.47
B						

Table 26: Triangle Lake pH taken every 4 h on July 26-27, 1994.
Values were used to calculate CO₂ flux due to respiration over 24 h.

Date- Depth m	1415	1815	2215	0230	0615	1015
0	7.11	7.52	7.55	7.52	7.53	7.47
1	7.23	7.49	7.58	7.48	7.48	7.43
2	7.23	7.46	7.63	7.46	7.45	7.43
3	7.45	7.50	7.71	7.50	7.44	7.45
4	7.25	7.53	7.85	7.54	7.51	7.45
5	7.17	7.57	8.08	7.58	7.52	7.46
6	7.28	7.59	7.63	7.59	7.53	7.51
7	7.42	7.85	7.80	7.92	7.83	7.73
8	7.33	8.00	8.36	8.57	8.22	8.25
9	6.94	8.48	8.51	8.57	8.49	8.32
B						

APPENDIX K

Chlorophyll-a concentration.

Table 27. Kookoo Lake chlorophyll-a profiles June, July and August 1993 and 1994 (mg/m³). Samples were taken at the surface in 1993.

Date- Depth m	6/93	7/93	8/93	6/94	7/94	8/94
0	*	*	*	0.072	0.144	0.360
1				0.216	0.216	0.432
2				0.216	0.216	0.504
3				0.144	0.288	0.504
4				0.144	0.216	0.576
5				0.216	0.216	0.792
6				0.216	0.216	0.648
7				0.216	0.432	0.936
8				0.216	0.432	1.224
9				0.288	0.504	2.016
mean				0.182	0.257	0.645

* samples did not preserve

Table 28. Triangle Lake chlorophyll-a profiles June, July and August 1993 and 1994. Samples were taken at the surface in 1993.

Date- Depth m	6/93	7/93	8/93	6/94	7/94	8/94
0	*	*	*	0.144	0.288	0.216
1				0.216	0.216	0.288
2				0.216	0.288	0.144
3				0.288	0.360	0.432
4				0.360	0.288	0.432
5				0.432	0.216	0.288
6				0.360	0.792	0.432
7				0.360	0.792	0.144
8				0.360	0.432	0.144
9				1.440	7.344	0.360
mean				0.328	0.605	0.289

* samples did not preserve

Table 29. Total grams per lake of chlorophyll-a in Kookoo and Triangle Lake calculated from samples in June, July and August 1994.

Date- Lake	6/94	7/94	8/94
Kookoo Lake	14.3	20.2	50.8
Triangle Lake	45.5	84.1	40.2

APPENDIX L

Nutrient profiles.

Table 30. Kookoo Lake nitrogen profiles for June, July and August 1993 and 1994. Measurements are in mg/L combining nitrate and nitrate as nitrate.

Date- Depth m	6/93	7/93	8/93	6/94	7/94	8/94
0				0.0695	0.0727	0.0629
1	0.03	0.01	0.01	0.0648	0.0826	0.0570
2	0.02	0.01	0.02	0.0708	0.0839	0.0550
3	0.02	0.02	0.02	0.0714	0.0800	0.0517
4	0.02	0.02	0.02	0.0760	0.0741	0.0510
5	0.02	0.01	0.00	0.0708	0.0695	0.0576
6	0.02	0.02	0.09*	0.0662	0.0734	0.0576
7	0.03	0.01	0.06*	0.0662	0.0648	0.0556
8	0.00	0.02	0.03	0.0616	0.0681	0.0616
9	0.03	0.01	0.03	0.0537	0.0635	0.0570
B						

* high value probably due to equipment contamination

Table 31. Triangle Lake nitrogen profiles for June, July and August 1993 and 1994. Measurements are in mg/L combining nitrate and nitrate as nitrate.

Date- Depth m	6/93	7/93	8/93	6/94	7/94	8/94
0		**		0.0280	0.0398	0.0065
1	0.01*	0.02	0.01	0.0306	0.0392	0.0054
2		0.01	0.01	0.0319	0.0362	0.0037
3		0.02	0.02	0.0293	0.0366	0.0065
4		0.01	0.01	0.0208	0.0346	0.0040
5		0.01	0.01	0.0188	0.0366	0.0034
6			0.01	0.0194	0.0294	0.0037
7			0.02	0.0175	0.0313	0.0037
8			0.02	0.0181	0.0389	0.0034
9			0.05	0.0155	0.0116	0.0028
B						

- * Lake was still ice-covered
- ** Leaky raft prohibited a complete profile

Table 32. Kookoo Lake ammonia profiles for June, July and August 1993 and 1994. Measurements are in mg/L.

Date- Depth m	6/93	7/93	8/93	6/94	7/94	8/94
0	*	*	*	0.0011	0.0034	0.0075
1				0.0027	0.0034	0.0051
2				0.0035	0.0026	0.0048
3				0.0019	0.0026	0.0027
4				0.0022	0.0014	0.0065
5				0.0024	0.0046	0.0049
6				0.0016	0.0032	0.0070
7				0.0006	0.0018	0.0040
8				0.0013	0.0083	0.0061
9				0.0537	0.0077	0.0040
B						

* levels too low to detect with Hach Kits

Table 33. Triangle Lake ammonia profiles for June, July and August 1993 and 1994. Measurements are in mg/L.

Date- Depth m	6/93	7/93	8/93	6/94	7/94	8/94
0	*	*	*	0.0016	0.0160	0.0075
1				0.0037	0.0200	0.0051
2				0.0016	0.0056	0.0048
3				0.0054	0.0185	0.0027
4				0.0029	0.0099	0.0065
5				0.0035	0.0054	0.0049
6				0.0014	0.0083	0.0070
7				0.0081	0.0140	0.0040
8				0.0035	0.0080	0.0061
9				0.0158	0.0382	0.0040
B						

* levels too low to detect with Hach Kits

Table 34. Kookoo Lake SRP profiles for June, July and August 1993 and 1994. Measurements are in mg/L. Values in 1993 were below detectable levels with Hach kits.

Date- Depth m	6/93	7/93	8/93	6/94	7/94	8/94
0				0.00197	0.00396	0.01253
1	0.00	0.00	0.05	0.00396	0.00368	0.00568
2	0.00	0.00	0.03	0.00197	0.00396	0.00282
3	0.01	0.00	0.01	0.00225	0.00254	0.0454
4	0.00	0.00	0.02	0.00168	0.00311	0.00225
5	0.01	0.00	0.01	0.00168	0.00282	0.00254
6	0.01	0.00	0.00	0.00082	0.00254	0.00311
7	0.01	0.00	0.01	0.00225	0.00339	0.00339
8	0.06	0.00	0.01	0.00282	0.00396	0.00339
9	0.01	0.00	0.01	0.00311	0.01053	0.00739
B						

Table 35. Triangle Lake SRP profiles for June, July and August 1993 and 1995. Measurements are in mg/L. Values in 1993 were below detectable levels with Hach kits.

Date- Depth m	6/93	7/93	8/93	6/94	7/94	8/94
0		**		0.01196	0.01253	0.00653
1	0.01*	0.00	0.00	0.00311	0.00568	0.00539
2		0.00	0.00	0.00311	0.00282	0.00369
3		0.00	0.00	0.00197	0.00454	0.00653
4		0.00	0.00	0.00368	0.00225	0.00396
5		0.00	0.00	0.00282	0.00254	0.00339
6			0.00	0.00197	0.00311	0.00368
7			0.00	0.01053	0.00339	0.00368
8			0.00	0.00368	0.00339	0.00339
9			0.00	0.00425	0.00739	0.00282
B						

* lake was still ice-covered

** leaky raft prevented a complete profile

APPENDIX M

Problems encountered during the study.

There were numerous problems associated with the nature of conducting this study far within the boundaries of a wilderness. Operation of mechanized equipment is prohibited in Wilderness areas. Getting the equipment to the study site was difficult, and the amount of gear that could be taken was limited. Horses were used to pack equipment to a base camp, and it had to be backpacked the last 2-3 km and 300 m of elevation to the study site.

Contamination of glassware was a constant problem as it had to be reused for all runs in the field. The nutrient profiles done in 1993 showed the effects of this contamination as did the alkalinity measurements. To address this problem, glassware was rinsed a minimum of four times in 1994, and alkalinity was conducted three times and averaged.

It was also necessary to leave equipment in the field for the summer. This allowed a two-man raft to be destroyed by rodents, and patching efforts were minimally successful. This caused an incomplete profile of Triangle Lake in July of 1993, and an absence of the light penetration measurement in Kookoo Lake in August of 1993.

Leaving equipment in the field also caused problems with the batteries, which constantly needed to be replaced. The temperature gauge on the DO meter became inoperative as the batteries ran down (often from the cold), and temperatures were obtained using a Kemmerer bottle, and the temperature setting on the pH meter. The battery terminals on the pH meter corroded in the field and needed to be replaced.

Blood work on the fish had to be eliminated as it was impossible to centrifuge in the field. It is suggested that microhematocrit tubes with EDTA preservative be tried as a way of preserving blood samples.

Nutrient levels were too low for accuracy with Hach Field Kits. Samples were subsequently packed on ice, packed out in a cooler, and frozen, prior to analysis in the Priscu lab at MSU.

Decomposition of samples was another problem associated with this study. Chlorophyll-a specimens from 1993 did not preserve well, and samples were not used. All phytoplankton samples decomposed prior to analysis.

The weather proved to be a challenge as well. Triangle Lake was ice covered for the June 1993 sampling, and both Lakes were ice-covered during the last week of June, 1995. The weather also prohibited one of the 4-h diel samplings during July 1994 in Kookoo Lake. The extended ice-cover in 1995 also affected the restricted growth of 1 year old stocked trout, resulting in sizes too small to be collected with gill nets.

Fish are stocked in the A-B Wilderness via helicopter. The 1994 stocking of trout in Triangle Lake is unaccounted for, and it is unsure whether the entire plant did not survive, or if the fish were stocked in the wrong lake.

The substrate of both lake outlets is primarily boulder, and low water flows caused erratic readings on the flow-meter. The location of the outlet stream measurements was changed in 1994 for Triangle Lake to address this problem. This was not possible in Kookoo Lake, and in August, 1994 measurements were impossible.

APPENDIX N

Volume profiles of Kookoo and Triangle Lake

Table 36. Volume profiles for Kookoo Lake and Triangle Lake

Depth m	Kookoo Lake in m ³	Triangle Lake in m ³
0-1	20569	24145
1-2	13858	21444
2-3	10346	18743
3-4	8738	16576
4-5	7431	14972
5-6	6279	13394
6-7	5109	11342
7-8	3794	8763
8-9	2381	6134
9-10	222	3383
10-11		650

APPENDIX O

Differential Titration of 5.3 and 7.5 mg/L CaCO_3 Solutions

Table 37. Differential titration values for pH change per .25 mL of .01M HCl using CaCO₃ solutions. A 5.3 mg/L solution corresponds to the alkalinity of Triangle Lake in July 1994, and a 7.5 mg/L solution corresponds to the alkalinity of Kookoo Lake in July 1994.

mL of 0.01M HCl	5.3 mg/L CaCO ₃ solution pH	7.5 mg/L CaCO ₃ solution pH
0.00	8.66	8.85
0.25	8.51	
0.5	8.37	8.70
0.75	8.00	8.60
1.00	7.62	8.45
1.25	7.40	8.20
1.50	7.25	7.90
1.75	7.13	7.45
2.00	6.95	7.23
2.25	6.86	7.12
2.50		7.02
2.75		6.95
3.00		6.85
3.25		6.77

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